ES&H Division

SLAC-I-720-0A24E-002

# Specification

for

# Seismic Design

of

# Buildings, Structures, Equipment, and Systems

at the

# Stanford Linear Accelerator Center

*Stanford Linear Accelerator Center*

December 4, 2000

This document, *Specification for Seismic Design of Buildings, Structures, Equipment and Systems at the Stanford Linear Accelerator Center*, has been reviewed and accepted by the following:

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This document was designed and published by the ES&H Division Office for SLAC's internal use.

Document Title: Specification for Seismic Design of Buildings, Structures, Equipment, and Systems at the Stanford Linear Accelerator Center

Original Publication Date: August 5, 1999

Revision Date: December 4, 2000

Original Source: Environment, Safety, and Health Division

Reference Document Number: SLAC-1-720-0A24E-002

Work supported by Department of Energy contract DE-AC03-76SF00515

# INTRODUCTION

In the recent past, SLAC Earthquake Design Specifications have recognized the proximity of the Laboratory to the San Andreas Fault by increasing the "Z" factor in formulae for base shear from 0.4 to 0.6 in the Uniform Building Code. This increase caused the designer to provide for earthquake forces one and one-half times the levels provided in the Code. In addition, SLAC has required all construction to meet the maximum horizontal ground surface accelerations for performance category PC-2 in DOE-STD-1020-94, "Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities". The PC-2 ground acceleration at SLAC is 0.59 or 0.6 when rounded to one significant figure.

The 1997 Uniform Building Code has caught up to SLAC concerns and practice. This new SLAC Seismic Specification accepts the 1997 Code with no modification of the "Z" factor or its equivalents. Indeed, the "Z" factor plays very little role in the new Code. It has been supplanted by a calculation method that uses factors that vary with distance from known fault locations and provides greater forces as one approaches the fault. Comparison of base shear calculations using the 1997 Code and the 1994 Code with Z=0.6 shows little difference for structures located at SLAC.

The Spectral Response Curve in the new Uniform Building Code is very conservative. Both the Department of Energy and the Uniform Building Code allow one to use site-specific curves when derived by knowledgeable experts. The new SLAC Earthquake Design Specification uses curves derived by Earth Sciences Associates for the design of the BaBar Detector[1] and made slightly more conservative for periods greater than 0.8 seconds by Roland Sharpe, Seismic Structural Engineering Consultant to SLAC. These curves have been found consistent with those provided by Woodward-Clyde for Stanford University. Alternatively, one may use the Code curve for conservative design.

This Design Specification assumes that buildings, structures, equipment, and systems should suffer very little damage from a moment magnitude ($M_w$) 7.0 earthquake on the proximate section of the San Andreas Fault, and should be "life safe" for $M_w$ 7.5. These two earthquake standards currently are required for Stanford University design and analysis of construction projects. SLAC should be able to operate within a few months of the magnitude 7.0 event if its buildings and structures meet these Specifications and appropriate budget and manpower are available for recovery. A much greater amount of work and funding would be required to regain operational status after a $M_w$ 7.5 event.

This Design Specification incorporates both the 1997 Uniform Building Code and information on building and structure performance first introduced in "Performance Based Seismic Engineering of Buildings" by the Structural Engineers Association of California in 1995 and later in their "Recommended Lateral Force Requirements and Commentary" in 1996 (Sixth Edition). This Specification extends the method to cover situations specific to SLAC.

Extensive tables of performance levels appear in this Specification to assist the designer in defining the behavior of buildings, structures, equipment, and systems to earthquake-induced loads. The minimum performance requirement for SLAC is 7.0. "Life Safe" structures have ratings greater than 4.5. Eighteen original SLAC buildings designed by ABA, the architectural-engineering firm that designed SLAC in the early 1960s, were evaluated by five structural engineering firms. The ratings averaged 7.3 (standard deviation 0.7, range 2.5, minimum 6.0). SLAC policy as stated here is to equal or exceed the quality (rating 7.0 or greater) of original construction when installing new buildings, structures, equipment, and systems. Additional engineering review must be given to any structure with a rating below 6.0, consistent with avoiding threats to life safety. Immediate action is required for structures with ratings of 4.5 or below.

No earthquake of magnitude $M_w$ 7.0 or greater has yet occurred in a highly industrialized, highly populated area of the United States. The SLAC site is vulnerable to such an event on the proximate section of the San Andreas Fault, of magnitude from $M_w$ 7.0 to $M_w$ 7.5, with a probability of the order of 0.2 in the next thirty years. Vulnerabilities exist with lower damage levels but with similar probabilities for an earthquake of $M_w$ 7.0 or greater on the Hayward or Calaveras faults, and possibly on the southern segment of the San Andreas fault from Black Mountain (just south of Page Mill Road) to San Juan Bautista[2 & 3]. The collective probability for all of these events is given as 0.67 in the next thirty years[2].

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[1] *SLAC BABAR Detector Site-Specific Response Spectra*, Project 117.9501, ESA Consultants, April, 1995

[2] *Probabilities of large earthquakes in the San Francisco Bay Region*, US Geological Survey Circular 1053, 1990.

[3] *The Black Mountain Asperity: Seismic Hazard of the Southern San Francisco Peninsula, California*, C.H. Scholz, Geophysical Research Letters, 12, 10 October 1985, and *Evaluation of Site Response and Design*

Finally, a comment must be made about the relative sizes and effects of the 1906 San Francisco and the 1989 Loma Prieta earthquakes. The 1906 earthquake was $M_w$ 7.9, the Loma Prieta 6.9. The duration of the 1906 earthquake was 45 to 60 seconds, the Loma Prieta, 15 seconds. The length of the rupture for the 1906 event was 430 km from San Juan Bautista to Cape Mendocino. The length of rupture for the Loma Prieta was 40 km centered in a forested and mountainous region east of Santa Cruz and 120 km south of San Francisco. The energy release by the 1906 earthquake was more than 16 times greater than the Loma Prieta.

The design earthquake for SLAC is closer to the 1906 earthquake than the Loma Prieta. The design event assumes an epicenter near Crystal Springs Reservoir with a rupture that moves south passing 1.0 km to the west of the Linear Accelerator. Ground shaking will be severe, and will have a duration similar to the 1906 earthquake. Ground shaking intensity will be described by Modified Mercalli Levels VIII or IX.

Level VIII exhibits the following:

> Damage to masonry: none to partial collapse. Fall of stucco and some masonry walls. Twisting, fall of chimneys, factory stacks, monuments, towers, and elevated tanks. Frame houses moved on foundations if not bolted down; loose panel walls thrown out. Branches broken from trees. Changes in flow or temperature of springs and wells. Cracks in wet ground and on steep slopes.

Level IX:

> General panic. Masonry heavily damaged or destroyed. General damage to foundations. Frame structures, if not bolted, shifted off foundations. Frames wracked. Serious damage to reservoirs. Underground pipes broken. Conspicuous cracks in ground. In alluvial areas sand and mud ejected, earthquake fountains, sand craters.

Clearly, the effects of the Loma Prieta earthquake do not provide an adequate experience of what will occur during the design earthquake. Loma Prieta was much weaker, shorter, and further away than the event for which we must design.

# 1. PURPOSE

The purpose of this Specification is to provide seismic safety standards (exceeding *Life Safe)* for SLAC buildings, structures, equipment, and systems, and to define a method for specifying structural and nonstructural performance. *Life Safe* does not guarantee that SLAC will be damage-free after an earthquake. The Structural Engineers Association of California provides the following caveat also suitable for this Specification:

"***Damage Levels.*** Structures designed in conformance with this Specification should, in general, be able to:

1. Resist a minor level of earthquake ground motion without damage;

2. Resist a moderate level of earthquake ground motion without structural damage, but possibly experience some nonstructural damage;

3. Resist a major level of earthquake ground motion - of an intensity equal to the strongest either experienced or forecast, for the building site - without collapse, but possibly with some structural as well as nonstructural damage.

It is expected that structural damage, even in a major earthquake, will be limited to a repairable level for structures that meet these (Specifications). In some instances, damage may not be economically repairable. The level of damage depends upon a number of factors, including the intensity and duration of ground shaking,

*Earthquake Motions; Stanford University, Palo Alto, California*, Woodward and Clyde Consultants, Oakland, California, May 22, 1995

structure configuration, type of lateral force resisting system, materials used in the construction, and construction workmanship."[4]

"***No Guarantee.*** Conformance to these Requirements does not constitute any kind of guarantee or assurance that significant structural damage will not occur in the event of design level earthquake ground motion. To fulfill the life safety objective of these Requirements, there are requirements that provide for structural stability in the event of extreme structural deformations and requirements that protect the vertical load carrying system from fracture or buckling at these extreme states. While damage to the primary structural system may be either negligible or significant, repairable or virtually irreparable, it is reasonable to expect that a well-planned and constructed structure will not collapse in a major earthquake. The protection of life is reasonably provided, but not with complete assurance."[5]

# 2. APPLICABILITY OF SPECIFICATION

The design and construction of all buildings, structures, equipment, and programmatic systems, or modifications or additions to such existing facilities shall meet the requirements outlined in this Specification. This Specification shall be applied in addition to other DOE and Federal regulations applicable to SLAC. The Specification is to be followed by engineers and architects providing design services for buildings, structures, equipment or systems or modifications thereto.

The seismic resistance capacity of the entire building, structure, equipment or system must be improved to meet the requirements of this Specification if:

1. More than 25 percent of the area of a building or structure is modified or added
2. The function is changed
3. The seismic resistance capability of the building, structure, equipment or system is changed by more than 15 percent
4. The seismic performance factor of the building, structure, system or equipment is judged to be below 6.0 in Tables 2 through 12

Definitions:

Building: A roofed structure that is suitable for housing people, material, or equipment. Included are sheds and other roofed improvements that provide partial protection from the weather.

Equipment: An item such as a pump, valve, or relay, or an element of a larger array such as a length of pipe, elbow, or reducer.

Facility: Buildings, utilities, structures, and other fixed systems and equipment installed therein.

Structure: Any improvement that is not a building or a utility constructed on or in the land. Examples of structures include tunnels, bridges, retaining walls, antenna towers, tanks, fixed cranes, roads, and sidewalks.

System: A collection of components to perform a function such as piping, cable trays, conduits, or HVAC.

[4] *Recommended Lateral Force Requirements and Commentary*, Seismology Committee, Structural Engineers Association of California, 1996, C101.1.1

[5] ibid.C101.1.2

# 3. CODES AND SPECIFICATIONS

The provisions of the 1997 Uniform Building Code shall apply with the following modifications:

1. Spectral acceleration curves in Figures 1 and 2 shall be used in the design of buildings and structures.
2. Spectral acceleration curves in Figures 3 and 4 shall be used in the design of mechanical and electrical systems and equipment.

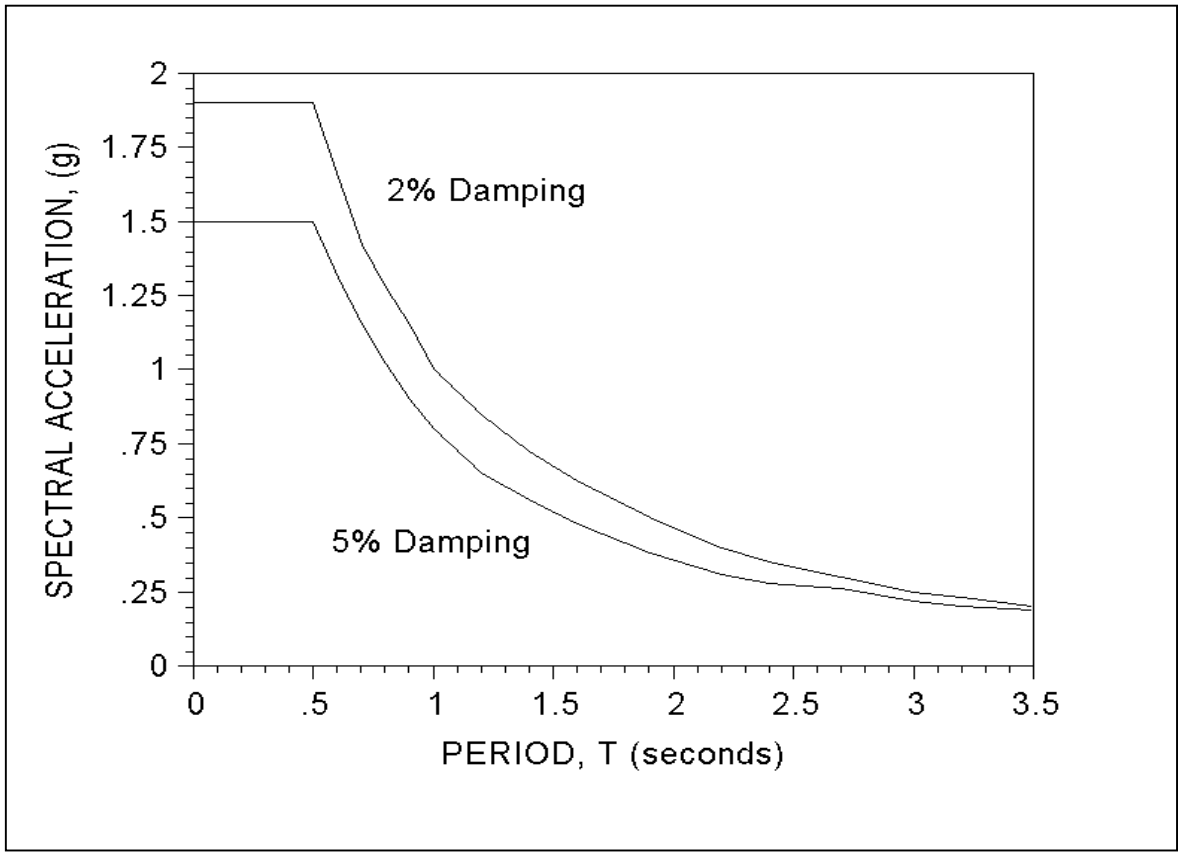


**Figure 1. Response Spectra for Civil Construction – Horizontal Motions**

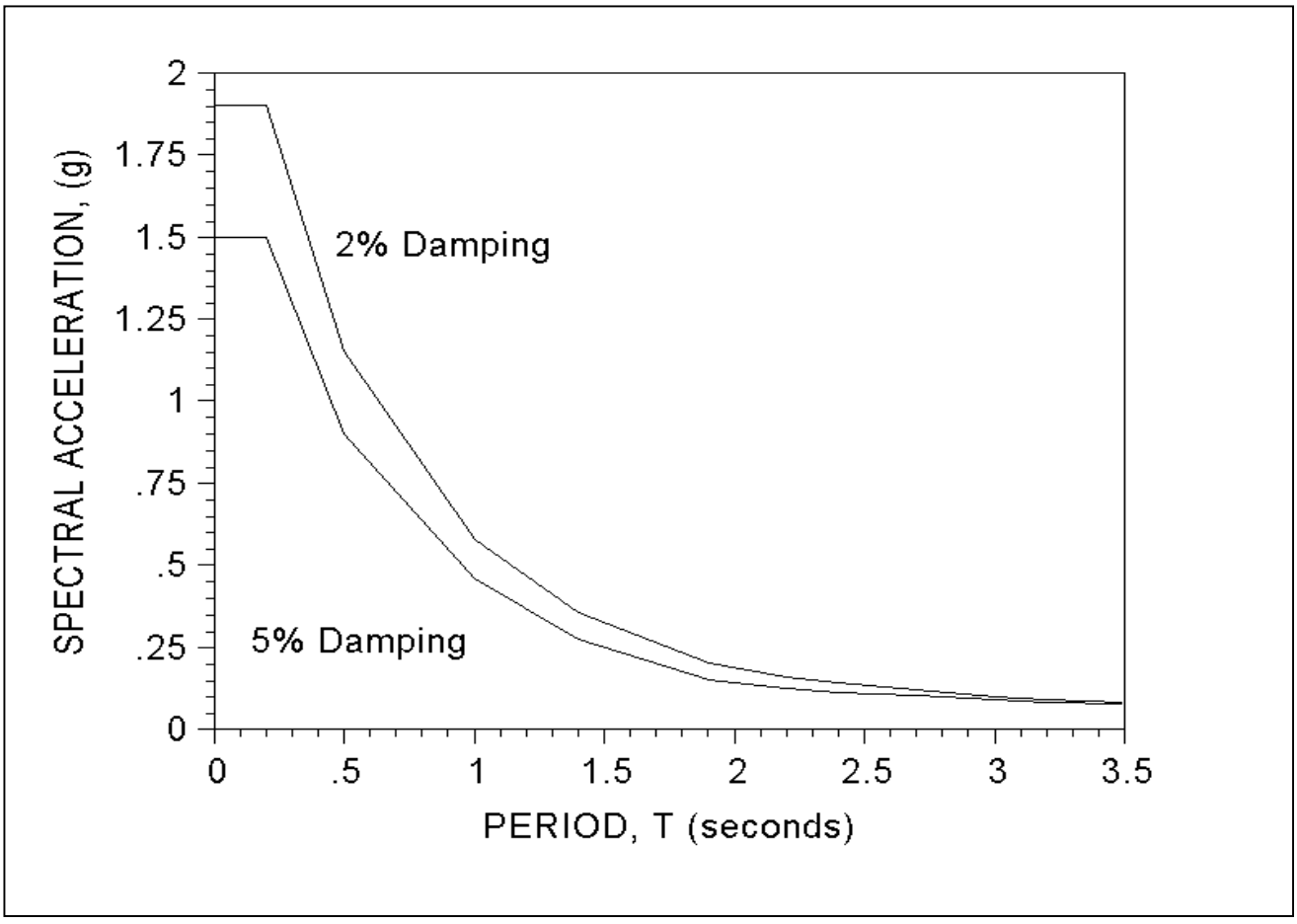


**Figure 2. Response Spectra for Civil Construction – Vertical Motion**

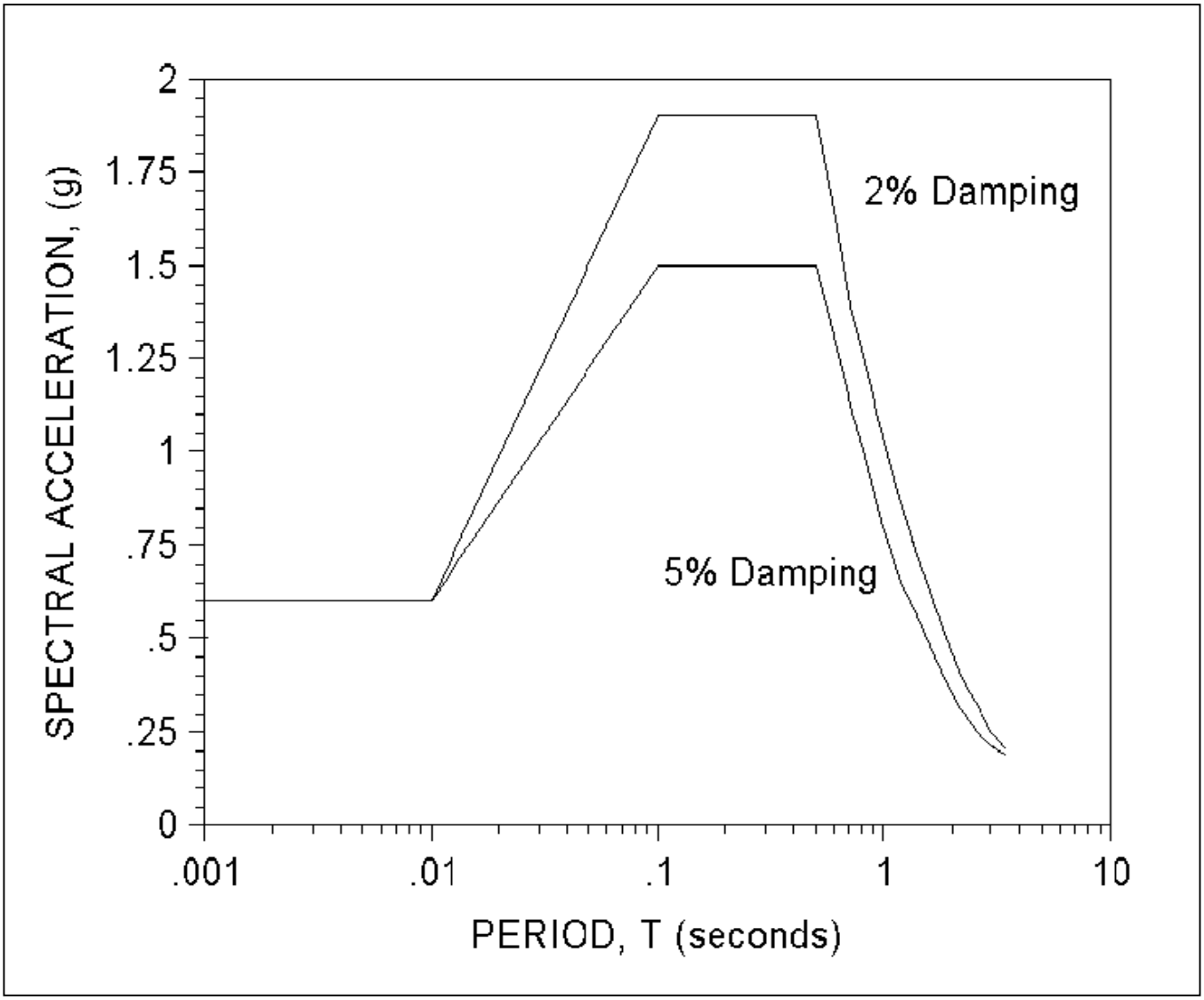


**Figure 3. Response Spectra for Mechanical Systems - Horizontal Motions**

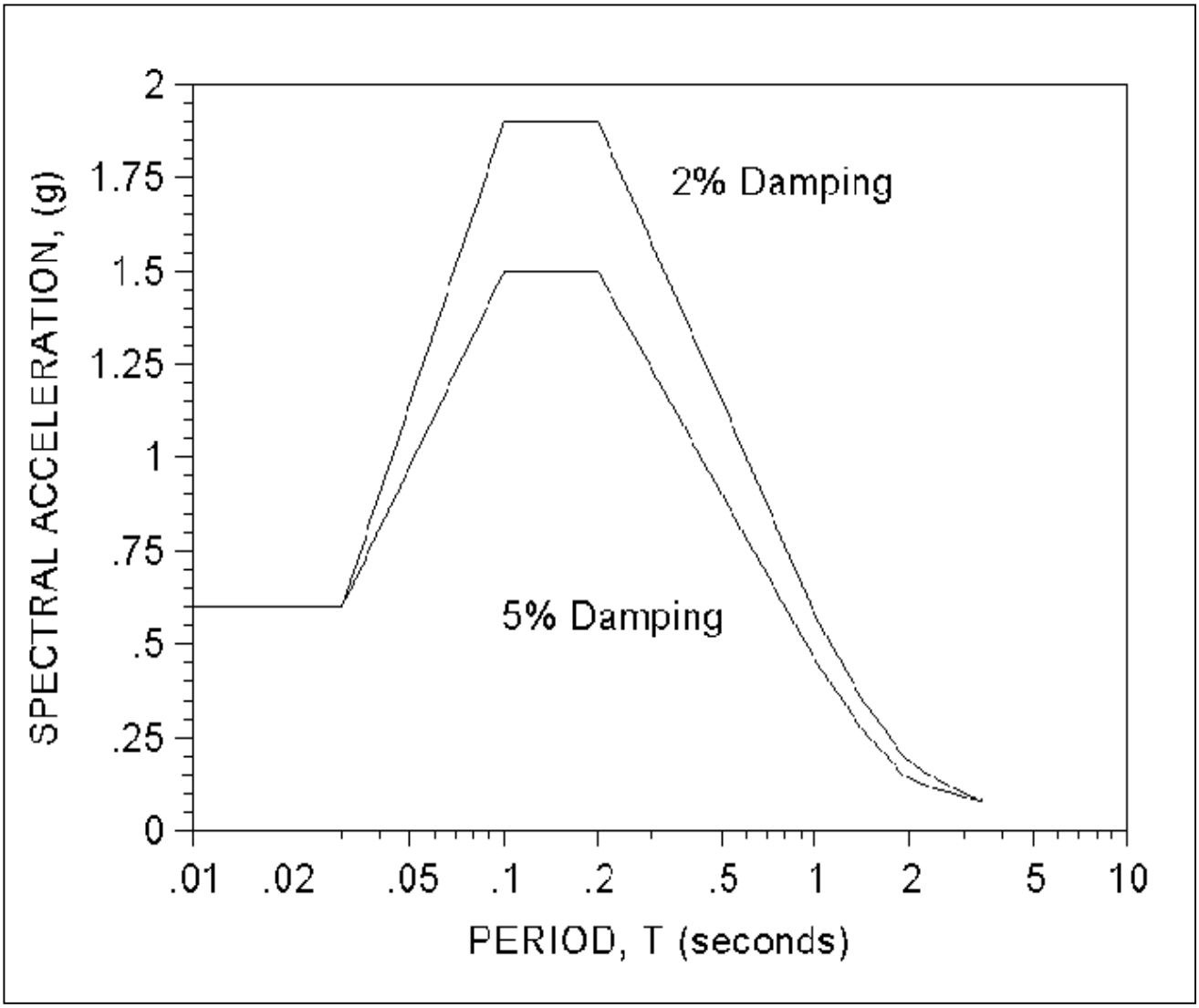


**Figure 4. Response Spectra for Mechanical Systems - Vertical Motion**

# 4. CLASSIFICATION OF SLAC FACILITIES

Buildings, structures, equipment and systems shall be assigned to one of two classes listed in Table 1.

**Table 1: Functional Classification of Building, Structures, Equipment and Systems**

| Class | Occupancy or Structural Function | 1997 Uniform Building Code Equivalent |
|---|---|---|
| **A** | Emergency Command Centers and Hazardous Facilities | Occupancy Categories 1 and 2, Table 16-K (reproduced in Appendix I) |
| **B** | General Occupancy and Use Buildings, Structures, Equipment and Systems | Occupancy Categories 3, 4, and 5 of Table 16-K (reproduced in Appendix I) |

# 5. SEISMIC PERFORMANCE LEVELS

Seismic performance levels shall be established for each building, structure, equipment and system according to its functional classification. The performance level shall be assigned to six separate components of the building, structure, equipment or system:

1. Structural Framing (SF)

   The structural framing includes all elements of the structure required to support gravity loads and resist lateral forces induced by wind or seismic ground motions. The Structural Framing System shall be designed for the required seismic performance level.

2. Egress Systems (ES)

   Viability of egress from a building after an earthquake is vital, both for exiting of occupants and access by search and rescue personnel. Therefore, the design of facilities shall carefully consider avenues of egress. The Egress Systems shall be designed for the required seismic performance level.

3. Nonstructural Building Systems (NBS)

   Nonstructural Building Systems include architectural elements such as interior partitions, ceilings, lighting fixtures, and exterior cladding of the structure, HVAC systems, elevators, electrical supply and control systems, and other systems such as fire sprinklers, toilets, and plumbing. Nonstructural Building Systems shall be designed for the required seismic performance level.

4. Contents Performance (CPF)

   The response to earthquake motions of building contents can impact life safety. Bookshelves, file cabinets and other furnishings can move abruptly or overturn and injure occupants or block doorways or corridors, thus preventing egress and slowing search and rescue. The building contents shall be properly restrained or anchored so as to meet the required seismic performance levels.

5. Lifeline Utilities Systems (LLS)

   The continued functioning or restart of a building or a programmatic system after an earthquake will be dependent on the availability of potable water, cooling water, electric power, sanitary sewerage, natural gas,

and telecommunications. Lifeline Utilities Systems within and their connections to the facility shall be designed for the required performance level.

6. Programmatic Systems (PS)

   The continued functioning or at least nominal downtime and repairable damage after a Design Earthquake event is important for most programmatic facilities and systems. These systems include but are not limited to the linear accelerator or extensions thereto, power supplies, modulators, magnets, klystron assemblies, vacuum pump and systems, deflectors, wave guide assemblies, cabinets for equipment, control and instrumentation, shielding block structures and similar elements. The Programmatic Systems shall be designed to meet the required seismic performance level.

## Required Performance Levels

Required performance levels for the two building, structure, equipment, and system classes are listed in Table 2.

**Table 2: Seismic Performance Levels for Functional Classification**

| Class | Functional Classification | Seismic Performance Level |
|---|---|---|
| **A** | Emergency Command Centers and Hazardous Facilities | 8.5 - 10 |
| **B** | General Occupancy and Use Buildings, Structures, Equipment and Systems | 7.0 - 8.5 |

The minimum expected performance for buildings, structures, equipment, and systems shall be as follows:

Class A: Emergency Command Centers, and Hazardous Facilities

Essentially no damage is expected. The building is usable and all equipment and services (lighting, electric power, potable water, communications and sanitary facilities) related to the building's basic occupancy and functions are available for use. Some temporary utilities may be required. In general, repair is not required.

Goal: In use as soon as possible, but not more than 3 hours downtime and no loss of life.

Class B: General Occupancy and Use Buildings, Structures, Equipment and Systems

Moderate damage to nonstructural elements and light damage to structural elements is acceptable; egress shall not be substantially impaired. Back-up systems and procedures may be required to permit continued use.

Goal: In use within 4 months and no loss of life.

General seismic Performance Levels are defined in Table 3. Tables 4 through 12 define Performance Levels for Systems, Structural Framing, Egress Systems, Nonstructural Building Systems, Contents, Lifeline Utility Systems, and Programmatic Systems. See Appendix II for an expanded definition of Functionality terms.

Equipment and systems must meet the requirements of the building class to which they are assigned. The seismic performance level of any building, structure, equipment or system may be set higher than the minimum for programmatic reasons.

**Table 3: Spectrum of Performance Levels[6]**

| **Level** | **10** | **8.5** | **6.5** | **4.5** | **2.5** | **1** |
|---|---|---|---|---|---|---|
| **Damage** | Negligible | Light | Moderate | Severe | Complete | |
| **Functionality** | Fully Operational | Operational | Life Safe | Near Collapse | Collapse | |
| **Performance** | No damage, continuous service. Continuous service, facility operates and functions after earthquake. Negligible structural and nonstructural damage. | Most operations and functions can resume immediately. Repair is required to restore some non-essential services. Damage is light. Structure is safe for occupancy immediately after earthquake. Essential operations are protected. Non-essential operations are disrupted. | Damage is moderate. Selected building systems, features or contents may be protected from damage. Life safety is generally protected. Structure is damaged but remains stable. Falling hazards remain secure. | Structural collapse prevented. Nonstructural elements may fail. Structural damage is severe, but collapse is prevented. Nonstructural elements fail. | Portions of primary structural system collapse. Complete structural collapse. | |

[6] *ibid.* based upon Appendix B, Figure AppB-2

**Table 4: General Damage Descriptions by Performance Levels and Systems[7]**

| System Description | Performance Levels | | | | |
|---|---|---|---|---|---|
| | 10 Fully Functional | 8.5 Operational | 6.5 Life Safe | 4.5 Near Collapse | 2.5 Collapse 1 |
| **Overall building damage** | Negligible | Light | Moderate | Severe | Complete |
| **Permissible transient drift** | <0.2%+/- | <0.5%+/- | <1.5%+/- | <2.5%=/- | >2.5%+/- |
| **Permissible permanent drift** | Negligible | Negligible | <0.5%+/- | <2.5%+/- | >2.5%+/- |
| **Vertical load carrying element damage** | Negligible | Negligible | Light to moderate, but substantial capacity remains to carry gravity loads. | Moderate to heavy, but elements continue to support gravity loads. | Partial to total loss of gravity load support. |
| **Lateral Load Carrying Element damage** | Negligible - generally elastic response; no significant loss of strength or stiffness. | Light - nearly elastic response; original strength and stiffness substantially retained. Minor cracking/yielding of structural elements; repair implemented at convenience. | Moderate - reduced residual strength and stiffness but lateral system remains functional. | Negligible residual strength and stiffness. No story collapse mechanisms but large permanent drifts. Secondary structural elements may completely fail. | Partial or total collapse. Primary elements may require demolition. |
| **Damage to architectural systems** | Negligible damage to cladding, glazing, partitions, ceilings, finishes, etc. Isolated elements may require repair at users convenience. | Light to moderate damage to architectural systems. Essential and select protected items undamaged. Hazardous materials contained. | Moderate to severe damage to architectural systems, but large falling hazards not created. Major spills of hazardous materials contained. | Severe damage to architectural systems. Some elements may dislodge and fall. | High dangerous falling hazards. Destruction of components. |
| **Egress systems** | Not impaired. | No major obstructions in exit corridors. Elevators may be restarted perhaps following minor servicing. | No major obstructions in exit corridors. Elevators may be out of service for an extended period. | Egress may be obstructed. | |

[7] *ibid.* based upon Appendix B, Table AppB-1

**Table 4, continued**

| System Description | Performance Levels | | | | |
|---|---|---|---|---|---|
| | 10 Fully Functional | 8.5 Operational | 6.5 Life Safe | 4.5 Near Collapse | 2.5 Collapse 1 |
| **Mechanical/Electrical/ Plumbing/Utility Systems** | Functional | Equipment essential to functional and fire/life safety systems operate. Other systems may require repair. Temporary utility service provided as required. | Some equipment dislodged or overturned. Many systems not functional. Piping, conduit ruptured. | Severe damage and permanent disruption of systems. | Partial or total destruction of systems. Permanent disruption of systems. |
| **Damage to contents** | Some light damage to contents may occur. Hazardous materials secured and undamaged. | Light to moderate damage. Critical contents and hazardous materials secured. | Moderate to severe damage to contents. Major spills of hazardous materials contained. | Severe damage to contents. Hazardous materials may not be contained. | Partial or total loss of contents. |
| **Repair** | Not Required | At owners/tenants convenience. | Possible - building may be closed. | Probably not practical. | Not possible. |
| **Effect on occupancy** | No effect. | Continuous occupancy possible. | Short term to indefinite loss of use. | Potential permanent loss of use. | Permanent loss of use. |

**Table 5: Performance Levels and Permissible Structural Damage - Vertical Elements[9]**

| Elements | Type | Performance Levels | | | |
|---|---|---|---|---|---|
| | | 10 Fully Functional | 8.5 Operational | 6.5 Life Safe | 4.5 Near Collapse 3 |
| **Concrete frames** | Primary | Negligible. | Minor hairline cracking (0.02"); limited yielding possible at a few locations; no crushing (strains below 0.003). | Extensive damage to beams; Spalling of cover and shear cracking (<1/8") for ductile columns. Minor spalling in non-ductile columns. Joints cracked <1/8" width. | Extensive cracking and hinge formation in ductile elements. Limited cracking and/or splice failure in some non-ductile columns. Severe damage in short columns. |
| | Secondary | Negligible. | Same as primary. | Extensive cracking and hinge formation in ductile elements. Limited cracking and/or splice failure in some non-ductile columns. Severe damage in short columns. | Extensive spalling in columns (possible shortening) and beams. Severe joint damage. Some reinforcing buckled. |
| **Steel moment frames** | Primary | Negligible. | Minor local yielding at a few places. No observable fractures. Minor buckling or observable permanent distortion of members. | Hinges form; local buckling of some beam elements; severe joint distortion. Isolated connection failure. A few elements may experience fracture. | Extensive distortion of beams and column panels. Many fractures at connections. |
| | Secondary | Negligible. | Minor local yielding at a few places. No observable fractures. Minor buckling or observable permanent distortion of members. | Extensive distortion of beams and column panels. Many fractures at connections. | Extensive distortion of beams and column panels. Many fractures at connections. |
| **Braced Steel frames** | Primary | Negligible. | Minor yielding or buckling of braces. No out-of-plane distortions. | Many braces yield or buckle but do not totally fail; Many connections may fail. | Extensive yielding and buckling of braces. Many braces and their connections may fail. |
| | Secondary | Negligible. | Same as primary. | Same as primary. | Same as primary. |

[9] *ibid.* based upon Appendix B, Table AppB-2

**Table 5, Continued**

| Elements | Type | Performance Levels | | | |
|---|---|---|---|---|---|
| | | 10 Fully Functional | 8.5 Operational | 6.5 Life Safe | 4.5 Near Collapse 3 |
| **Concrete shear walls** | Primary | Negligible. | Minor hairline cracking (0.02") of walls. Coupling beams experience cracking <1/8" width. | Some boundary element distress including limited bar buckling; damage around openings; some crushing and flexural cracking; Coupling beams - extensive shear and flexural cracks; some crushing, but concrete generally remains in place. | Major flexural and shear cracks and voids; sliding at joints; extensive crushing and buckling of rebar; failure around openings; severe boundary element damage; Coupling beams shattered, virtually disintegrated. |
| | Secondary | Negligible. | Minor hairline cracking of walls, some evidence of sliding at construction joints, Coupling beams experience cracks < 1/8" width, minor spalling. | Major flexural and shear cracks; sliding at joints; extensive crushing; failure around openings; severe boundary element damage; Coupling beams shattered, virtually disintegrated. | Panels shattered virtually disintegrated. |
| **Unreinforced masonry infill walls** | Primary | Negligible. | Minor cracking (< 1/8") of masonry infills and veneers. Minor spalling in veneers at a few corner openings. | Extensive cracking and some crushing but wall remains in place; no falling units; Extensive crushing and spalling of veneers at corners of openings. | Extensive cracking and crushing; portions of face course shed. |
| | Secondary | Negligible. | Same as primary. | Same as primary. | Extensive cracking and crushing; portions of face course shed. |

**Table 5, Continued**

| Elements | Type | Performance Levels | | | |
|---|---|---|---|---|---|
| | | 10 Fully Functional | 8.5 Operational | 6.5 Life Safe | 4.5 Near Collapse 3 |
| **Unreinforced masonry bearing walls** | Primary | Negligible. | Minor cracking (< 1/8") of masonry infills and veneers. Minor spalling in veneers at a few corner openings. No observable out-of-plane offsets. | Extensive cracking, noticeable in-plane offsets of masonry and minor out-of-plane offsets. | Extensive cracking. Face course and veneer may peel off. Noticeable in-plane and out-of-plane offsets. |
| | Secondary | Negligible. | Same as primary. | Same as primary. | Same as primary. |
| **Reinforced masonry walls** | Primary | Negligible. | Minor cracking (< 1/8"). No out-of-plane offsets. | Extensive cracking (< 1/4"), distributed throughout wall. Some isolated crushing. | Crushing; extensive cracking; damage around openings and at corners; some fallen units. |
| | Secondary | Negligible. | Same as primary. | Crushing; extensive cracking; damage around openings and at corners; some fallen units. | Panels shattered virtually disintegrated. |
| **Wood stud walls** | Primary | Negligible. | Distributed minor hairline cracking of gypsum and plaster veneers. | Moderate loosening of connections and minor splitting of members. | Connections loose, nails partially withdrawn, some splitting of members and panel; veneers shear off. |
| | Secondary | Negligible. | Same as primary. | Connections loose, nails partially withdrawn, some splitting of members and panel. | Sheathing shears off, let-in braces fracture and buckle, framing split and fractured. |
| **Foundations** | General | Negligible. | Minor settlement and negligible tilting. | Total settlements < 6 inches and differential settlements < 1/2 inch in 30 feet. | Major settlements, and tilting. |

**Table 6: Performance Levels and Permissible Structural Damage - Horizontal Elements[10]**

| System | Performance Levels | | | |
|---|---|---|---|---|
| | 10 Fully Functional 8.5 | Operational 6.5 | Life Safe 4.5 | Near Collapse 3 |
| **Metal deck diaphragms** | Negligible. | Connections between deck units and from deck to framing intact. Minor distortions. | Some localized failure of welded connections of deck to framing and between panels; minor local buckling of deck. | Large distortion with buckling of some units and tearing of many welds an seam attachments. |
| **Wood diaphragms** | Negligible. | No observable loosening, withdrawal of fasteners, or splitting of sheathing or framing. | Some splitting at connections, loosening of sheathing, observable withdrawal of fasteners, splitting of framing and sheathing. | Large permanent distortion with partial withdrawal of nails and splitting of elements. |
| **Concrete diaphragms** | Negligible. | Distributed hairline cracking and a few minor cracks (< 1/8") or larger size. | Extensive cracking (< 1/4") and local crushing and spalling. | Extensive crushing and observable offset across many cracks. |

[10] *ibid.* based upon Appendix B, Table AppB-3

## Table 7: Performance Levels and Permissible Damage - Egress Systems

| System | Performance Levels | | | |
|---|---|---|---|---|
| | 10 Fully Functional | 8.5 Operational | 6.5 Life Safe | 4.5 Near Collapse 3 |
| **Egress systems**<br>**Exit Corridor obstructions** | Not impaired. | No major obstructions in exit corridors. Elevators may be restarted perhaps following minor servicing. | No major obstructions in exit corridors. Elevators may be out of service for an extended period. | Egress may be obstructed. |
| **Contents obstructing exit hallways** | Negligible effects. | Minor damage; some sliding and overturning. | Extensive damage from sliding, overturning, leaks, falling debris, etc. | Extensive damage from sliding, overturning, leaks, falling debris, etc. |
| **Doors** | Negligible damage. | Minor damage. | Distributed damage; some wracked and jammed doors. | Distributed damage; many wracked and jammed doors. |
| **Elevators** | Elevators operational with isolated exceptions. | Elevators generally operational; most can be restarted. | Some elevators out of service. | Many elevators out of service. |
| **Emergency lighting systems** | Functional. | Functional. | Functional. | Not functional. |

**Table 8: Performance Levels and Permissible Nonstructural Building Systems Damage - Architectural Elements[11]**

| System | Performance Levels | | | |
|---|---|---|---|---|
| | 10 Fully Functional | 8.5 Operational | 6.5 Life Safe | 4.5 Near Collapse 3 |
| **Cladding** | Negligible damage. | Connections yield; some cracks or bending in cladding. | Severe distortion in connections; distributed cracking, bending, crushing and spalling of cladding elements; some fracturing of cladding; falling of panels prevented. | Severe damage to connections and cladding; some falling of panels. |
| **Glazing** | Generally no damage; isolated cracking possible. | Some broken glass; falling hazards avoided. | Extensive broken glass; some falling hazard. | General shattered glass and distorted frames; widespread falling hazards. |
| **Partitions** | Negligible damage; some hairline cracks at openings. | Cracking to about 1/16" at openings; crushing and cracking at corners. | Distributed damage; some severe cracking, crushing and wracking in some areas. | Severe wracking and damage in many areas. |
| **Ceilings** | Generally negligible damage; isolated suspended panel dislocations or cracks in hard ceilings. | Minor damage; some suspended ceilings disrupted, panels dropped; minor cracking in hard ceilings. | Extensive damage; dropped suspended ceilings, distributed cracking in hard ceilings. | Most ceilings damaged; most suspended ceilings dropped, severe cracking in hard ceilings. |
| **Light fixtures** | Negligible damage; pendant fixtures sway. | Minor damage; some pendant lights broken; falling hazards prevented. | Many broken light fixtures; falling hazards generally avoided in heavier fixtures (> 20 lbs +/-). | Extensive damage; falling hazards occur. |
| **Doors** | Negligible damage. | Minor damage. | Distributed damage; some wracked and jammed doors. | Distributed damage; many wracked and jammed doors. |
| **Elevators** | Elevators operational with isolated exceptions. | Elevators generally operational; most can be restarted. | Some elevators out of service. | Many elevators out of service. |

[11] *ibid.* based upon Appendix B, Table AppB-4

## Table 9: Performance Levels and Permissible Damage - Mechanical/Electrical/Plumbing Systems[12]

| System | Performance Levels | | | |
|---|---|---|---|---|
| | 10 Fully Functional | 8.5 Operational | 6.5 Life Safe | 4.5 Near Collapse 3 |
| **Mechanical Equipment** | Negligible damage, all remain in service. | Minor damage. Some units, not essential to function out-of-service. | Many units non-operational; some slide or overturn. | Most units non-operational; many slide or overturn; some pendant units fall. |
| **Ducts** | Negligible damage. | Major damage, but systems remain in service. | Some ducts rupture; some supports fail, but ducts do not fall. | Most systems out of commission; some ducts fall. |
| **Piping** | Negligible damage. | Minor damage. Minor leaking may occur. | Some pipes rupture at connections; many supports fail; few fire sprinkler heads fail. | Many pipes rupture; supports fail; some piping systems collapse. |
| **Fire sprinkler systems** | Negligible damage.. | Minor damage. Minor leaking may occur. | Some pipes rupture at connections; many supports fail. | Many pipes rupture; supports fail; some piping systems collapse. |
| **Fire alarm systems** | Functional. | Functional. | Not functional. | Not functional. |
| **Emergency lighting systems** | Functional. | Functional. | Functional. | Not functional. |
| **Electrical equipment** | Negligible damage. | Minor damage; panels restrained, isolated loss of function in secondary systems. | Moderate damage; panels restrained from overturning; some loss of function and service in primary systems. | Extensive damage and loss of service. |

[12] *ibid.* based upon Appendix B, Table AppB-5

## Table 10: Performance Levels and Permissible Damage - Contents[13]

| System | Performance Levels | | | |
|---|---|---|---|---|
| | 10 Fully Functional | 8.5 Operational | 6.5 Life Safe | 4.5 Near Collapse 3 |
| **Furniture** | Negligible effects. | Minor damage; some sliding and overturning. | Extensive damage from sliding, overturning, leaks, falling debris, etc. | Extensive damage from sliding, overturning, leaks, falling debris, etc. |
| **Office equipment** | Negligible effects. | Minor damage; some sliding and overturning. | Extensive damage from sliding, overturning, leaks, falling debris, etc. | Extensive damage from sliding, overturning, leaks, falling debris, etc. |
| **Computer systems** | Operational. | Minor damage; some sliding and overturning. Mostly functional. | Extensive damage from sliding, overturning, leaks, falling debris, etc. | Extensive damage from sliding, overturning, leaks, falling debris, etc. |
| **File cabinets** | Negligible damage. | Minor damage; some sliding and overturning. | Extensive damage from sliding, overturning, leaks, falling debris, etc. | Extensive damage from sliding, overturning, leaks, falling debris, etc. |
| **Bookshelves** | Negligible effects. | Minor damage; some overturning and spilling. | Extensive damage from leaks, falling debris, overturning, etc. | Extensive damage from leaks, falling debris, overturning, etc. |
| **Storage racks & cabinets** | Negligible effects; overturning restrained. | Moderate damage; overturning restrained; some spilling. | Extensive damage from leaks, falling debris, overturning, spilling, etc. | Extensive damage from leaks, falling debris, overturning, spilling, etc. |
| **Art works, collections** | Minor damage; overturning restrained. | Moderate damage; overturning restrained; some spilling. | Extensive damage from leaks, falling debris, overturning, spilling, etc. | Extensive damage from leaks, falling debris, overturning, spilling, etc. |
| **Hazardous materials** | Negligible damage; overturning and spillage restrained. | Negligible damage; overturning and spillage restrained. | Minor damage; overturning and spillage generally restrained. | Severe damage; some hazardous materials released. |

[13] *ibid.* based upon Appendix B, Table AppB-6

## Table 11: Performance Levels and Permissible Damage - Lifeline Utility Systems

| System | Performance Levels | | | |
|---|---|---|---|---|
| | 10 Fully Functional | 8.5 Operational | 6.5 Life Safe | 4.5 Near Collapse 3 |
| **Potable Water to the Building** | Fully functional. Negligible damage. Water at full pressure. | Water under pressure; minor leaking may occur. May have limited or interrupted service. | Some leaking may occur; may have limited or interrupted service. | Extensive leaking may occur; little pressure. Service will be limited or interrupted. |
| **Potable Water in the Building** | Fully functional. Negligible damage. | Water under pressure; minor leaking may occur. May have limited or interrupted service. | Some leaking may occur; may have limited or interrupted service. | Extensive leaking may occur; little pressure. Service will be limited or interrupted. |
| **Sanitary Sewer to the Building** | Fully functional. Negligible damage. | Minor damage; minor leaking may occur. May have limited or interrupted service. | Some leaking may occur; may have limited or interrupted service. | Extensive leaking may occur; little pressure. Service will be limited or interrupted. |
| **Sanitary Sewer in the Building** | Fully functional. Negligible damage. | Minor damage; minor leaking may occur. May have limited or interrupted service. | Some leaking may occur. May have limited or interrupted service. | Extensive leaking may occur. May have lengthy service interruption. |
| **Electrical Supply to the Building** | Fully functional. Negligible damage. | Minor damage. May have limited or interrupted service. | Some damage. May have limited or interrupted service. | Extensive damage. May have limited or interrupted service. |
| **Electrical Supply in the Building** | Fully functional. Negligible damage. | Minor damage. May have limited or interrupted service. | Some damage. May have limited or interrupted service. | Extensive damage. May have limited or interrupted service. |
| **Natural Gas Supply to the Building** | Fully functional. Negligible damage. | Minor damage. May have limited or interrupted service. | Some damage. May have limited or interrupted service. | Extensive damage. May have limited or interrupted service. |
| **Natural Gas Supply in the Building** | Fully functional. Negligible damage. | Minor damage. May have limited or interrupted service. | Some damage. May have limited service or interrupted service. | Extensive damage. May have limited or interrupted service. |
| **Telecommunications to the Building** | Fully functional. Negligible damage. | Minor damage. May have limited or interrupted service. | Some damage. May have limited or interrupted service. | Extensive damage. May have limited or interrupted service. |
| **Telecommunications in the Building** | Fully functional. Negligible damage. | Minor damage. May have limited or interrupted service. | Some damage. May have limited or interrupted service. | Extensive damage. May have limited or interrupted service. |

## Table 12: Performance Levels/Damage Descriptions - Programmatic Systems

| System | Performance Levels | | | |
|---|---|---|---|---|
| | 10 Fully Functional | 8.5 Operational | 6.5 Life Safe | 4.5 Near Collapse 3 |
| **General** | Detailed analysis reveals adequate restraint and anchorage of internal elements to be fully functional post quake. | Detailed analysis reveals adequate restraint and anchorage of internal elements to incur only minor damage. | Restraint or anchorage adequate to prevent overturning or excessive movement which would endanger personnel or block exits. | Restraint or anchorage inadequate to prevent overturning or excessive movement which would endanger personnel or block exits. |
| **Power Supplies, Modulators** | Detailed analysis reveals adequate restraint and anchorage of internal elements to be fully functional post quake. | Detailed analysis reveals adequate restraint and anchorage of internal elements to incur only minor damage. | Restraint or anchorage adequate to prevent overturning or excessive movement which would endanger personnel or block exits. | Restraint or anchorage inadequate to prevent overturning or excessive movement which would endanger personnel or block exits. |
| **Magnets, klystron systems** | Detailed analysis reveals adequate restraint and anchorage of internal elements to be fully functional post quake. | Detailed analysis reveals adequate restraint and anchorage of internal elements to incur only minor damage. | Restraint or anchorage adequate to prevent overturning or excessive movement which would endanger personnel or block exits. | Restraint or anchorage inadequate to prevent overturning or excessive movement which would endanger personnel or block exits. |
| **Equipment and cabling** | Detailed analysis reveals adequate restraint and anchorage of internal elements to be fully functional post quake. | Detailed analysis reveals adequate restraint and anchorage of internal elements to incur only minor damage. | Restraint or anchorage adequate to prevent overturning or excessive movement which would endanger personnel or block exits. | Restraint or anchorage inadequate to prevent overturning or excessive movement which would endanger personnel or block exits. |
| **Other Systems - Wave guides, vacuum pumps, Shielding tunnels, Detectors** | Detailed analysis reveals adequate restraint and anchorage of internal elements to be fully functional post quake. | Detailed analysis reveals adequate restraint and anchorage of internal elements to incur only minor damage. | Restraint or anchorage adequate to prevent overturning or excessive movement which would endanger personnel or block exits. | Restraint or anchorage inadequate to prevent overturning or excessive movement which would endanger personnel or block exits. |

# 6. QUALITY ASSURANCE AND CONTROL

It is essential that the Architectural-Engineering firms or individuals selected for design of facilities or additions to existing facilities is qualified, experienced professionals. The selection process shall emphasize this aspect. The SLAC Earthquake Safety Committee shall review project design criteria prior to retaining the firm. The SLAC Earthquake Safety Committee shall review and approve drawings and calculations prior to construction.

SLAC shall retain an experienced California licensed structural engineer specializing in seismic design as a third party peer reviewer for structural aspects of a project when:

- Construction is of significant size or cost,
- Personnel safety hazards may be present,
- Building or structure has an unusual or irregular configuration, or
- SLAC Earthquake Safety Committee sets a requirement.

The performance of a building or structure during an earthquake is largely dependent on the configuration of the lateral force resisting system, the adequacy of design detailing and connections, and on how well the construction conforms to the drawings and specifications. The final design shall be reviewed for adequacy by the peer reviewers and recommended changes made. Appropriate inspections shall be performed during construction as required by applicable codes.

Special inspection shall be provided for Class A facilities as described in the 1997 Uniform Building Code, Chapter 17:

> **SECTION 1702 - STRUCTURAL OBSERVATION** Structural observation shall be provided in Seismic Zone 3 or 4 when one of the following conditions exists:
> 1. The structure is defined in Table 16-K as Occupancy Category 1, 2 or 3,
> 2. The structure is required to comply with Section 403,
> 3. The structure is in Seismic Zone 4, *Na* as set forth in Table 16-S is greater than one, and a lateral design is required for the entire structure,
>
> **EXCEPTION:** One- and two-story Group R, Division 3 and Group U Occupancies and one- and two-story Groups B, F, M and S Occupancies.
>
> 4. When so designated by the architect or engineer of record, or
> 5. When such observation is specifically required by the building official.
>
> The owner shall employ the engineer or architect responsible for the structural design, or another engineer or architect designated by the engineer or architect responsible for the structural design, to perform structural observation as defined in Section 220. Observed deficiencies shall be reported in writing to the owner's representative, special inspector, contractor and the building official. The structural observer shall submit to the building official a written statement that the site visits have been made and identifying any reported deficiencies that, to the best of the structural observer's knowledge, have not been resolved.

This Specification for Seismic Design shall be maintained and updated as necessary by the SLAC Earthquake Safety Committee or successor organization.

# APPENDIX I

## (Reproduced from the 1997 Uniform Building Code)

### TABLE 16-K-OCCUPANCY CATEGORY

| OCCUPANCY CATEGORY | OCCUPANCY OR FUNCTIONS OF STRUCTURE | SEISMIC IMPORTANCE FACTOR, *I* | SEISMIC IMPORTANCE [14] FACTOR, *Ip* | WIND IMPORTANCE FACTOR, *Iw* |
|---|---|---|---|---|
| 1. Essential facilities[15] | Group I, Division 1 Occupancies having surgery and emergency treatment areas<br>Fire and police stations<br>Garages and shelters for emergency vehicles and emergency aircraft<br>Structures and shelters in emergency-preparedness centers Aviation control towers<br>Structures and equipment in government communication centers and other facilities required for emergency response<br>Standby power-generating equipment for Category 1 facilities<br>Tanks or other structures containing housing or supporting water or other fire-suppression material or equipment required for the protection of Category 1, 2 or 3 structures | 1.25 | 1.50 | 1.15 |
| 2. Hazardous facilities | Group H, Divisions 1, 2, 6 and 7 Occupancies and structures therein housing or supporting toxic or explosive chemicals or substances<br>Nonbuilding structures housing, supporting or containing quantities of toxic or explosive substances that, if contained within a building, would cause that building to be classified as a Group H, Division 1, 2 or 7 Occupancy | 1.25 | 1.50 | 1.15 |
| 3. Special occupancy structures[16] | Group A, Divisions 1, 2 and 2.1 Occupancies<br>Buildings housing Group E, Divisions 1 and 3 Occupancies with a capacity greater than 300 students Buildings housing Group B Occupancies used for college or adult education with a capacity greater than 500 students<br>Group I, Divisions 1 and 2 Occupancies with 50 or more resident incapacitated patients, but not included in Category 1<br>Group I, Division 3 Occupancies<br>All structures with an occupancy greater than 5,000 persons<br>Structures and equipment in power-generating stations, and other public utility facilities not included in Category 1 or Category 2 above, and required for continued operation | 1.00 | 1.00 | 1.00 |
| 4. Standard occupancy structures[3] | All structures housing occupancies or having functions not listed in Category 1, 2 or 3 and Group U Occupancy towers | 1.00 | 1.00 | 1.00 |
| 5. Miscellaneous structures | Group U Occupancies except for towers | 1.00 | 1.00 | 1.00 |

[14] The limitation of $I_p$ for panel connections in Section 1633.2.4 shall be 1.0 for the entire connector.

[15] Structural observation requirements are given in Section 1702.

[16] For anchorage of machinery and equipment required for life-safety systems, the value of $I_p$ shall be taken as 1.5.

# Appendix II

## PERFORMANCE LEVELS[17]

At the very heart of performance based engineering are the performance levels. The definitions given below define each of these ranges in terms of the maximum damage and lowest performance which would qualify within the intent of the performance level.

A. Fully Operational [or Fully Functional]: Level 8.5 to 10

A performance level in which essentially no damage has occurred. If a building responds to an earthquake within this performance level, the consequences to the building user community are negligible. The building remains safe to occupy and it is expected that post-earthquake damage inspectors utilizing the ATC-20 methodology would post the building with a green placard. The building is occupiable and all equipment and services related to the building's basic occupancy and functions are available for use. In general, repair is not required.

B. Operational: Level 6.5 to 8.5

A performance level in which moderate damage to nonstructural elements and contents, and light damage to structural elements has occurred. The damage is limited and does not compromise the safety of the building for occupancy. Post-earthquake damage inspectors utilizing the ATC-20 methodology would be expected to post the building with a green placard. It would be available for occupancy for its normal intended function immediately following the earthquake, however, damage to some contents, utilities and nonstructural components may partially disrupt some normal functions. Back-up systems and procedures may be required to permit continued use. Repairs may be instituted at the owners' and tenants' convenience.

C. Life Safe: Level 4.5 to 6.5

A performance level in which moderate damage to structural and nonstructural elements and contents has occurred. The structure's lateral stiffness and ability to resist additional lateral loads has been reduced, possibly to a great extent, however, some margin against collapse remains. No major falling debris hazards have occurred. Egress from the building is not substantially impaired, albeit elevators and similar electrical and mechanical devices may not function. In the worst case, post-earthquake damage inspectors, using the ATC-20 methodology, would be expected to post such a building with a yellow placard. In such cases the building would not be available for immediate post-earthquake occupancy. The building would probably be repairable, although it may not be economically practical to do so.

[17] Quoted from "Performance Based Seismic Engineering of Buildings"
Structural Engineers Association of California
Volume II, page 1.3

D. Near Collapse: Level 2.5 to 4.5

An extreme damage state in which the lateral and vertical load resistance of the building have been substantially compromised. Aftershocks could result in partial or total collapse of the structure. Debris hazards may have occurred and egress may be impaired, however, all significant vertical load carrying elements (beams, columns, slabs, etc.) continue to function. In the worst case, post-earthquake inspectors, using the ATC-20 methodology, would be expected to post such a building with a red placard. The building will likely be unsafe for occupancy and repair may not be technically or economically feasible.

E. Partial/Total Collapse: Level 1 to 2.5

An extreme damage state in which the vertical load resistance of the building has partially or totally collapsed. Post-earthquake damage inspectors, using the ATC-20 methodology, would be expected to post such a building with a red placard. The building will be unsafe for occupancy and the building probably will need to be demolished.