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ASCE STANDARD

American Society of Civil Engineers

Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities

This document uses both the International System of Units (SI) and customary units.

ASCE

SEI

Structural Engineering Institute

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Developed by
Working Group for Seismic Design Criteria for Nuclear Facilities
Dynamic Analysis of Nuclear Structures Subcommittee
Nuclear Standards Committee

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STANDARDS

In April 1980, the Board of Direction approved ASCE Rules for Standards Committees to govern the writing and maintenance of standards developed by the Society. All such standards are developed by a consensus standards process managed by the Codes and Standards Activities Committee. The consensus process includes balloting by the Balanced Standards Committee, which is composed of Society members and nonmembers, balloting by the membership of ASCE as a whole, and balloting by the public. All standards are updated or reaffirmed by the same process at intervals not exceeding 5 years.

The following Standards have been issued:

ANSI/ASCE 1-82 N-725 Guideline for Design and Analysis of Nuclear Safety Related Earth Structures
ANSI/ASCE 2-91 Measurement of Oxygen Transfer in Clean Water
ANSI/ASCE 3-91 Standard for the Structural Design of Composite Slabs and ANSI/ASCE 9-91 Standard Practice for the Construction and Inspection of Composite Slabs
ASCE 4-98 Seismic Analysis of Safety-Related Nuclear Structures
Building Code Requirements for Masonry Structures (ACI 530-02/ASCE 5-02/TMS 402-02) and Specifications for Masonry Structures (ACI 530.1-02/ASCE 6-02/TMS 602-02)
SEI/ASCE 7-02 Minimum Design Loads for Buildings and Other Structures
ANSI/ASCE 8-90 Standard Specification for the Design of Cold-Formed Stainless Steel Structural Members
ANSI/ASCE 9-91 listed with ASCE 3-91
ASCE 10-97 Design of Latticed Steel Transmission Structures
SEI/ASCE 11-99 Guideline for Structural Condition Assessment of Existing Buildings
ANSI/ASCE 12-91 Guideline for the Design of Urban Subsurface Drainage
ASCE 13-93 Standard Guidelines for Installation of Urban Subsurface Drainage
ASCE 14-93 Standard Guidelines for Operation and Maintenance of Urban Subsurface Drainage
ASCE 15-98 Standard Practice for Direct Design of Buried Precast Concrete Pipe Using Standard Installations (SIDD)
ASCE 16-95 Standard for Load and Resistance Factor Design (LRFD) of Engineered Wood Construction
ASCE 17-96 Air-Supported Structures
ASCE 18-96 Standard Guidelines for In-Process Oxygen Transfer Testing
ASCE 19-96 Structural Applications of Steel Cables for Buildings
ASCE 20-96 Standard Guidelines for the Design and Installation of Pile Foundations
ASCE 21-96 Automated People Mover Standards—Part 1
ASCE 21-98 Automated People Mover Standards—Part 2
ASCE 21-00 Automated People Mover Standards—Part 3
SEI/ASCE 23-97 Specification for Structural Steel Beams with Web Openings
SEI/ASCE 24-98 Flood Resistant Design and Construction
ASCE 25-97 Earthquake-Actuated Automatic Gas Shut-Off Devices
ASCE 26-97 Standard Practice for Design of Buried Precast Concrete Box Sections
ASCE 27-00 Standard Practice for Direct Design of Precast Concrete Pipe for Jacking in Trenchless Construction
ASCE 28-00 Standard Practice for Direct Design of Precast Concrete Box Sections for Jacking in Trenchless Construction
SEI/ASCE/SFPE 29-99 Standard Calculation Methods for Structural Fire Protection
SEI/ASCE 30-00 Guideline for Condition Assessment of the Building Envelope
SEI/ASCE 31-03 Seismic Evaluation of Existing Buildings
SEI/ASCE 32-01 Design and Construction of Frost-Protected Shallow Foundations
EWRI/ASCE 33-01 Comprehensive Transboundary International Water Quality Management Agreement
EWRI/ASCE 34-01 Standard Guidelines for Artificial Recharge of Ground Water
EWRI/ASCE 35-01 Guidelines for Quality Assurance of Installed Fine-Pore Aeration Equipment
CI/ASCE 36-01 Standard Construction Guidelines for Microtunneling
SEI/ASCE 37-02 Design Loads on Structures During Construction
CI/ASCE 38-02 Standard Guideline for the Collection and Depiction of Existing Subsurface Utility Data
EWRI/ASCE 39-03 Standard Practice for the Design and Operation of Hail Suppression Projects
ASCE/EWRI 40-03 Regulated Riparian Model Water Code
ASCE/EWRI 42-04 Standard Practice for the Design and Operation of Precipitation Enhancement Projects
ASCE/SEI 43-05 Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities
ASCE/EWRI 44-05 Standard Practice for the Design and Operation of Supercooled Fog Dispersal Projects

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FOREWORD

Nuclear facilities are defined as facilities that process, store, or handle radioactive materials in a form and quantity that pose potential nuclear hazard to the workers, the public, or the environment. Due to the risk associated with such hazards, it is desirable that nuclear facilities have a lower probability that structural damage will be caused by earthquakes than do conventional facilities. This Standard provides seismic design criteria that are more stringent than normal building codes. The goal of this Standard is to ensure that nuclear facilities can withstand the effects of earthquake ground shaking with desired performance, expressed as probabilistic Target Performance Goals. Design for other earthquake effects (such as differential fault displacement and seismic slope instability) are not covered by this Standard. This Standard is intended for use in the design of new facilities and is to be used in conjunction with other national consensus standards specified herein.

This Standard can also be used for facilities handling explosives, toxic materials, or chemicals; for facilities where safety, mission, or investment protection are concerns; and where more stringent seismic criteria than provided by building codes are desired.

This Standard is intended to be used with ASCE 4, which provides criteria for seismic analysis of safety related nuclear facilities Structures, Systems and Components (SSCs); ACI 349 for concrete structures; AISC standards for steel structures; ASME standards for mechanical systems and components; IEEE standards for electrical systems and components; and ASCE 7 for minimum non-seismic design loads for buildings and other structures. This ASCE Standard specifies seismic load combinations.

This Standard uses the Target Performance Goal–based seismic design approach documented in U.S. Department of Energy Natural Phenomena Hazards (NPH) standards. This Standard is also consistent with the philosophy used in the National Earthquake Hazard Reduction Program (NEHRP) for seismic mitigation of new and existing facilities. The Standard uses input from ANSI/ANS Standard 2.26 to assign Seismic Design Categories (SDCs)* to SSCs. It provides requirements for determining design basis seismic loading using input from ANSI/ANS Standards 2.27 and 2.29, and it prescribes design criteria that are tied to structural Limit States.

ANS 2.26 employs a graded approach to ensure that the level of conservatism and rigor in design is appropriate for facility characteristics, such as hazards to workers, the public, and the environment. ANS 2.26 specifies five SDCs for classifying SSCs based on their importance and failure consequences. Each SSC has a specified numerical Target Performance Goal. ANS 2.26 also provides descriptive criteria to assist the designer in selecting an appropriate Limit State for use in the design of SSCs. Four Limit States are defined—A, B, C, and D—where A is short of collapse and D is essentially elastic behavior. This Standard specifies design criteria for load combinations, including earthquake ground shaking (i.e., stress, displacement, and ductility limits), such that these Limit States are not exceeded.

The combination of SDC and Limit State defines the Seismic Design Basis (SDB) for each SSC. Thus, an SSC with SDB-3C would use criteria for SDC-3 and Limit State C. A total of 20 SDBs are defined in ANS 2.26 that can match seismic design criteria to SSC safety function and importance, implementing a graded approach.

SDBs defined by SDC 1 and 2 are covered by the approach presented in ASCE 7. This Standard presents design and analysis requirements for SDBs defined by SDC 3, 4, and 5 and all Limit States. The approach presented for SDC 3, 4, and 5 has been adapted from that used in the U.S. Department of Energy Standard 1020, ASCE 4, and the U.S. Nuclear Regulatory Commission Standard Review Plan (NUREG-0800).

The intended user of this Standard is the designer or analyst involved in the design of a new nuclear structure, system, or component. The Standard is intended to provide a rational basis for the performance-based, risk-consistent seismic design of SSCs in nuclear facilities. Designers once were initiated into the field of probabilistic design by being taught that seismic performance categories for SSCs were established by DOE-STD-1020-94 and subsequent revisions. Each performance category was tied to a probabilistic performance goal that represented a target annual frequency of seismic-induced failure. However, these earlier design codes did not allow designers the freedom to select a Limit State (the permissible deformation limit for the SSC established from functional considerations). There has been a movement within the structural engineering community to give designers freedom to select the desired state of the facility following the Design Basis Earthquake (DBE, defined in ATC-40, FEMA 273 and FEMA 356, SEAOC-Vision 2000, and ASCE 31). The traditional design Limit State of providing life safety can now be expanded to include nuclear confinement, remain fully functional, or minimize operational loss.

* In this Standard, the term "Seismic Design Category" has a different meaning than in the International Building Code and ASCE 7.

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ACRONYMS/NOTATION

A_I	Arias intensity
A_R	Ground motion ratio
ACI	American Concrete Institute
AISC	American Institute of Steel Construction
AISI	American Iron and Steel Institute
ANS	American Nuclear Society
ANSI	American National Standards Institute
APE	Annual probability of exceedance
ASD	Allowable Stress Design
ASME	American Society of Mechanical Engineers
ATC	Applied Technology Council
AWWA	American Water Works Association
B&PVC	Boiler and Pressure Vessel Code
C	Capacity determined in accordance with building codes
CMAA	Crane Manufacturer Association of America
COV	Coefficient of variation
D	Total demand; also, distance to controlling earthquake; also, peak ground displacement
D_{NS}	Non-seismic demand
D_S	Elastic seismic demand
DBE	Design Basis Earthquake
DF	Design Factor
DOE	U.S. Department of Energy
DRS	Design Earthquake Response Spectrum: $DRS = DF \times UHRS$
EBF	Eccentrically Braced Frame
EES	Earthquake Experience Spectrum
ENA	Eastern North America
EUS	Eastern United States
EPRI	Electric Power Research Institute
LRFD	Load and Resistance Factor Design
F_μ	Inelastic energy absorption factor
$F_{\mu S}$	System inelastic energy absorption factor
FEMA	Federal Emergency Management Agency
FS	Factor of Safety
GIP	Generic Implementation Procedure
H_D	Mean annual hazard exceedance frequency: $H_D = R_P \times P_F$
IBC	International Building Code
IEEE	The Institute of Electrical and Electronics Engineers, Inc.
K	Capacity increase factor
LS	Limit State (A, B, C, or D)
M	Magnitude of controlling earthquake
N_y	Nyquist frequency
NEHRP	National Earthquake Hazard Reduction Program
NEMA	National Electrical Manufacturer Association
NEP	Non-Exceedance Probability
NFPA	National Fire Protection Association
NPH	Natural Phenomena Hazards
NPP	Nuclear Power Plant
NRC	U.S. Nuclear Regulatory Commission
PC	Performance Category
P_F	Mean annual frequency of unacceptable performance (Target Performance Goal)
PGA	Peak Ground Acceleration; A is also used for Peak Ground Acceleration
PSD	Power Spectral Density
PSHA	Probabilistic Seismic Hazard Assessment
QA	Quality Assurance
R_P	Probability Ratio: H_D / P_F
RBS	Reduced Beam Sections
RRS	Required Response Spectra
SA_f	Spectral Acceleration at natural frequency, f
SA_{PEAK}	Peak Spectral Acceleration
SAM	Seismic Anchor Motion
SDB	Seismic Design Basis
SDC	Seismic Design Category* (SDC-1, SDC-2, SDC-3, SDC-4, or SDC-5)
SF	Seismic Scale Factor
SMACNA	Sheet Metal and Air-Conditioning Contractors National Association
SMRF	Special Moment-Resisting Frame
SQUG	Seismic Qualification Utility Group
SRSS	Square root sum of squares
SSC	Structure, System, or Component
SSE	Safe Shutdown Earthquake
SSI	Soil-Structure Interaction
T_{sm}	Strong motion duration
TES	Test Experience Spectrum
TRS	Test Response Spectrum
UHRS	Uniform Hazard Response Spectra
USGS	U.S. Geological Survey
V	Peak Ground Velocity
ZPA	Zero Period Acceleration
α	Parameter used to determine Design Factor
ϕ	Capacity reduction factor

* In this Standard, the term "Seismic Design Category" has a different meaning than in the International Building Code and ASCE 7.

DEFINITIONS

ACCELEROGRAM. A representation (either recorded, modified recorded, or synthetic) of the acceleration of the ground during an earthquake. The accelerogram contains acceleration and time-data pairs.

RECORDED EARTHQUAKE ACCELEROGRAM. A time-history record of acceleration versus time that has been measured by a strong motion instrument during an earthquake.

MODIFIED RECORDED EARTHQUAKE ACCELEROGRAM. A time-history record of acceleration versus time that has been produced from a recorded earthquake time history, but in which the Fourier amplitudes have been scaled such that the resulting response spectrum envelops a target response spectrum. The Fourier phasing from the Recorded Earthquake Accelerogram is preserved in a Modified Recorded Earthquake Accelerogram.

SYNTHETIC EARTHQUAKE ACCELEROGRAM. A time-history record of acceleration versus time pairs that has been produced so that the resulting response spectrum envelops a target response spectrum.

ACTIVE COMPONENT. Components that must change state as part of their safety function during an earthquake.

ARIAS INTENSITY. A measure of the intensity of ground shaking that is obtained by integrating the square of the ground acceleration values over a specified time period. The Arias intensity is given as

$$A_I = \frac{\pi}{2g} \cdot \int_0^{t_m} a^2(t)dt$$

where $a(t)$ is the ground acceleration and t_m is the duration of the ground acceleration record.

ARIAS INTENSITY RISE TIME. Duration (time) needed to produce 5% of the total cumulative energy available in an earthquake accelerogram. If the total cumulative energy, E_{total}, is given as

$$E_{\text{total}} = \int_0^{\infty} a^2(t)dt$$

then the Arias Intensity Rise Time, $T_{0.05}$, is given as

$$(0.05)E_{\text{total}} = \int_0^{T_{0.05}} a^2(t)dt$$

BACKBONE CURVE. Monotonic representation of the nonlinear response of an element under consideration obtained by enveloping the load deformation curve of the element.

CAPACITY SPECTRUM METHOD. A nonlinear static analysis procedure (described in ATC-40) that provides a graphical representation of the expected seismic performance of a structure by the intersection of the structure's capacity spectrum with a response spectrum (demand spectrum) representation of the earthquake's displacement demand on the structure. The intersection is the performance point, and the displacement coordinate, d_p, of the performance point is the estimated displacement demand on the structure for the specified level of seismic hazard.

CONTROLLING EARTHQUAKE. The earthquake, for the particular return period and structural frequency range of interest, generated from the deaggregated hazard analysis for the predominant magnitude, M, and distance, D, pair.

DESIGN BASIS EARTHQUAKE (DBE). The description of the ground motion, defined in terms of the DRS, to be used for design. The DBE is obtained by following ANSI/ANS 2.27 and 2.29 for SSCs in SDC 3, 4, or 5.

DESIGN RESPONSE SPECTRA (DRS). Response spectra used for design. The DRS are equal to the product of the UHRS and the Design Factor and are defined at a control location in the free field.

DESIGN FACTOR (DF). The ratio between the DRS and the UHRS. The Design Factor is aimed at achieving the target annual probability of failure goals.

DESIGN TEAM. The responsible group charged with producing the design. Typically consists of a number of discipline-specific team members (e.g., structural, mechanical, electrical).

DIRECTIONAL CORRELATION COEFFICIENT. A measure of the degree of linear relationship between two earthquake accelerograms. For accelerograms X and Y, the directional correlation coefficient is given by

$$\rho_{XY} = \frac{\frac{1}{n}\sum_{i=1}^{n}[(X_i - \bar{x})(Y_i - \bar{y})]}{\sigma_X \sigma_Y}$$

where n is the number of discrete acceleration-time data points, $\bar{x}$ and $\bar{y}$ are the mean values, and σ_X and σ_Y are the standard deviations of X and Y, respectively.

DISTRIBUTION SYSTEMS. A system (i.e., collection of components) whose function is to distribute material/data (fluid, signals, power). Examples are piping, cable trays, conduit, and HVAC systems.

DOMINANT RESPONSE PARAMETER. The mode of behavior of the structural component that has the largest contribution to deflection. For example, shear is the dominant response parameter for a squat shear wall [aspect ratio (height/length) less than 2].

EFFECTIVE NATURAL FREQUENCY. The frequency of the single mode of response that dominates the structure or component response for multi–degree-of-freedom structures.

EFFECTIVE STIFFNESS FACTOR. Modifier (e.g., 0.5, 0.7) that is applied to the uncracked section properties of a reinforced concrete member to account for the softening effect that cracking has on the uncracked stiffness properties of interest.

EFFECTIVE STRUCTURAL FREQUENCY. See *Effective Natural Frequency.*

FACILITY. One or more buildings or structures, including systems and components, dedicated to a common function.

FOUNDATION ELEMENT. A structural component that is dedicated to transferring loads from the superstructure to the supporting soil.

FOURIER AMPLITUDE SPECTRUM. A plot of Fourier amplitude, $F(\omega)$, versus frequency, ω. $F(\omega)$ is the Fourier amplitude of the time history computed over the strong motion duration, T_{sm}.

SMOOTHED FOURIER AMPLITUDE SPECTRUM. An averaged Fourier amplitude spectrum, computed by averaging the amplitude values $F(\omega)$ over the frequency range of $\omega_i \pm 20\%$ at each frequency point, ω_i, over a moving frequency window.

FOURIER PHASE SPECTRUM. A plot of Fourier phase ϕ versus frequency, ω.

GRADED APPROACH. (From CFR 830.3.) The process of ensuring that the level of analysis, documentation, and actions used to comply with a requirement are commensurate with the following:

- Relative importance to safety, safeguards, and security;
- Magnitude of any hazard involved;
- Life cycle stage of a facility;
- Programmatic mission of a facility;
- Particular characteristics of a facility;
- Relative importance of radiological and nonradiological hazards; and
- Any other relevant factor.

GROUND MOTION SLOPE RATIO. Ratio of the spectral accelerations, frequency by frequency, from a seismic hazard curve corresponding to a 10-fold reduction in hazard exceedance frequency (see Eq. 2.2-2).

HAZARD. A source of danger (i.e., material, energy source, or operation) with the potential to cause illness, injury, or death to personnel (workers or the public), damage to an operation, or damage to the environment (without regard for the likelihood or credibility of accident scenarios or consequence mitigation).

HAZARD CURVE. See *Seismic Hazard Curve.*

HYSTERESIS LOOP. Nonlinear load-deformation loop of a structural component. The area enclosed by hysteresis loop is equivalent to the energy dissipated by the element in one complete loading and unloading cycle.

INELASTIC ENERGY ABSORPTION FACTOR (F_μ). A reduction factor used to reduce demand to account for inelastic behavior. The inelastic energy absorption factor is a function of the Limit State and the structural system or equipment configuration (see Tables 5-1 and 8-1).

IN-STRUCTURE RESPONSE SPECTRA. The response spectra generated from the seismic response at selected locations in a structure. In-structure response spectra are used for design of systems and components supported within a structure.

LIMIT STATE (LS). The limiting acceptable condition of the SSC. The Limit State may be defined in terms of a maximum acceptable displacement, strain, ductility, or stress. Four Limit States are specified in this Standard:

A = Short of collapse, but structurally stable
B = Moderate permanent deformation
C = Limited permanent deformation
D = Essentially elastic

LOAD PATH. The path of resistance consisting of structural or nonstructural members that the imposed load will follow from the point of origin (inertial forces at location of structure mass) to the point of final resistance (e.g., supporting soil).

MEAN ANNUAL HAZARD EXCEEDANCE FREQUENCY. The expected annual probability of exceedance. This value is used to determine earthquake acceleration from seismic hazard curves.

MEAN ANNUAL EXCEEDANCE FREQUENCY OF ACCEPTABLE PERFORMANCE. See *Target Performance Goal.*

NUCLEAR FACILITY. Includes both reactor and nonreactor facilities.

NONREACTOR NUCLEAR FACILITY. Facilities that contain activities or operations that involve radioactive and/or fissionable materials in such form and quantity that a nuclear hazard potentially exists to the employees, the general public, or the environment. Included are activities or operations that:

- Produce, process, or store radioactive liquid or solid waste, fissionable materials, or tritium;
- Conduct separations operations;

- Conduct irradiated materials inspection, fuel fabrication, decontamination, or recovery operations;
- Conduct fuel enrichment operations;
- Perform environmental remediation or waste management activities involving radioactive materials.

Linear accelerators and targets are considered nonreactor nuclear facilities. Incidental use and generation of radioactive materials in a facility operation (e.g., check and calibration sources and use of radioactive sources in research, experimental, and analytical laboratory activities, electron microscopes, and X-ray machines) would not ordinarily require the facility to be included in this definition.

NYQUIST FREQUENCY (N_y). Maximum frequency that can be represented by the time history discretization, $N_y = 1/(2\Delta t)$, where Δt is the time increment.

OVERDRIVE. Using too strong of a time history as input to the soil column so that nonlinear effects result in a larger soil response (soil strains) than would occur under the appropriate event. Overdriving the soil column could produce significantly different response spectra in the free field.

***P*-DELTA (*P*-Δ) EFFECT.** Additional moment induced in axial load-carrying members caused by lateral structural deformation. The *P*-Delta moment is the product of the axial force and the relative lateral displacement between the end points of the member.

PASSIVE COMPONENT. Components that do not require changing state as part of their safety function during an earthquake.

PEAK GROUND ACCELERATION (PGA). The maximum absolute value of the ground acceleration time history.

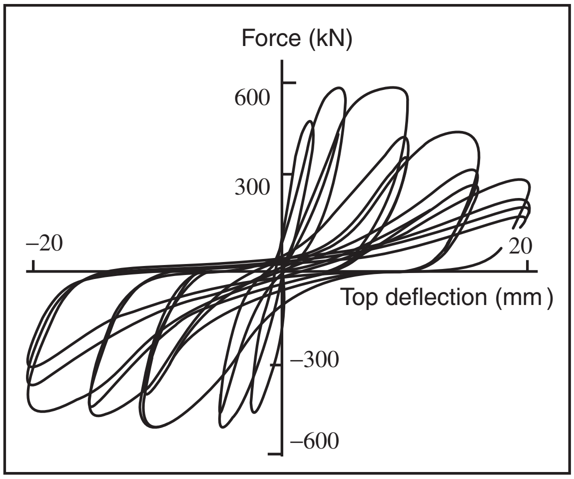
PEAK SPECTRAL ACCELERATION. The maximum acceleration response that a prescribed forcing function can produce in a single-degree-of-freedom oscillator (independent of the natural frequency of the oscillator).

PEER REVIEW. A formal review process in which an external party will review the methodology, results, and process by which a design is developed. The external party is independent of project schedule and budget constraints.

PERFORMANCE GOAL. The mean annual frequency of unacceptable performance that is specified, as a target, for the SSC SDC. Performance goals are specified in ANS 2.26.

PHASE SPECTRUM. See *Fourier Phase Spectrum.*

PINCHED HYSTERETIC BEHAVIOR. A characteristic of the load-deformation loop of a structural component subjected to cyclic loading that is marked by both strength and stiffness degradation in successive loading and unloading cycles beyond yield. See example below.



PLASTIC HINGE LENGTH. Region of plastic deformation; may be approximated by 1 beam depth.

POWER SPECTRAL DENSITY (PSD). A measure of the distribution of power in an accelerogram as a function of frequency. The PSD computed from an accelerogram is defined in terms of the Fourier amplitudes of the time history, $F(\omega)$, by the relation

$$PSD(\omega) = \frac{2|F(\omega)|^2}{2\pi T_{sm}}$$

where T_{sm} is the strong motion duration.

PROBABILITY RATIO (R_P). The ratio between the exceedance frequency of the DBE and the Target Performance Goal. The user may specify a unique value for a specific application.

PROBABILISTIC SEISMIC HAZARD ASSESSMENT (PSHA). A procedure used to develop seismic hazard curves and uniform hazard response spectra for determining the ground motion at a site to be used for seismic design. Criteria and guidance for conducting a PSHA are provided in ANSI/ANS 2.27 and 2.29.

REQUIRED RESPONSE SPECTRA (RRS). The representation of the response spectra that are required to qualify an SSC. The required response spectra will include factors required to meet probabilistic performance goals.

SAFE SHUTDOWN EARTHQUAKE (SSE). DBE for commercial nuclear power plants. Per 10 CFR 100, Appendix A, the SSE is that earthquake which is based upon an evaluation of the maximum earthquake potential considering the regional and local geology and seismology and specific characteristics of local subsurface material. It is that earthquake which produces the maximum vibratory ground motion for which certain SSCs are designed to remain functional. These SSCs are those necessary to ensure the following:

- Integrity of the reactor coolant pressure boundary,
- Capability to shut down the reactor and maintain it in a safe shutdown condition, or
- Capability to prevent or mitigate the consequences of accidents, which could result in potential offsite exposures.

The SSE is developed by the nuclear power plant owner and reviewed by the U.S. Nuclear Regulatory Commission.

SEISMIC DEMAND. The demand imposed on the SSC being evaluated at the earthquake level under consideration. The seismic demand may be expressed in terms of force, moment, stress, displacement, rotation, or strain.

SEISMIC DESIGN BASIS (SDB). The combination of SDC (3, 4, or 5) and Limit State (A, B, C, or D) that determines the DBE and acceptance criteria for designing SSCs. For example, SDB-3C would use criteria given in this Standard for SDC-3 and Limit State C.

SEISMIC DESIGN CATEGORY (SDC). A category assigned to an SSC that is a function of the severity of adverse radiological and toxicological effects of the hazards that may result from the seismic failure of the SSC on workers, the public, and the environment. SSCs may be assigned to SDCs that range from 1 to 5. For example, a conventional building whose failure may not result in any radiological or toxicological consequences is assigned to SDC-1; a safety-related SSC in a nuclear material processing facility with a large inventory of radioactive material may be placed in SDC-5. In this Standard, the term "Seismic Design Category" has a different meaning than in the International Building Code and Standard 7. The definition from ASCE 7 follows: "A classification assigned to a structure based on its Seismic Use Group and the severity of the design earthquake ground motion at the site." ANS 2.26 provides guidance on the assignment of SSCs to SDCs.

SEISMIC HAZARD CURVE. Description of the ground motion parameter of interest as a function of annual frequency of exceedance. The seismic hazard curve is determined from a probabilistic seismic hazard assessment following the guidance in ANSI/ANS 2.27 and 2.29.

SLAB/WALL MOMENT FRAME. A moment-resisting frame, composed of both walls and slabs, that resists seismic lateral loading by out-of-plane bending. Slab/wall moment frames may include column and beam elements. The span of the slab is predominately one-way from wall to wall, although two-way action is utilized for concentrated loads and around floor openings. Out-of-plane bending of the walls and slabs resists both gravity and lateral loads. Longitudinal loads are resisted by in-plane shear in the slabs and shear walls. Reinforced concrete structures, which resist lateral seismic load, in two orthogonal directions, with shear walls and diaphragms, are not slab/wall moment frames.

SPECTRAL ACCELERATION (SA). The maximum acceleration response of a single-degree-of-freedom oscillator with a known frequency, f, and viscous damping, β, subjected to a prescribed forcing function or earthquake ground motion time history.

SPECIAL MOMENT-RESISTING FRAME (SMRF). A steel or reinforced concrete moment-resisting frame specially detailed to provide ductile behavior that complies with the requirements given in ANSI/AISC 341-02, or with the special seismic provisions of ACI 349.

STRONG MOTION DURATION (T_{sm}). The duration (in seconds) in which the cumulative energy in an accelerogram moves from 5% to 75% of the total cumulative energy. See *Arias Intensity Rise Time*.

STRUCTURE, SYSTEM, OR COMPONENT (SSC). A *structure* is an element, or a collection of elements, to provide support or enclosure, such as a building, free-standing tanks, basins, dikes, or stacks. A *system* is a collection of components assembled to perform a function, such as piping, cable trays, conduits, or HVAC. A *component* is an item of mechanical or electrical equipment, such as a pump, valve, or relay, or an element of a larger array, such as a length of pipe, elbow, or reducer. In this Standard, each SSC is assigned an SDB that is based on the SDC and the Limit State that are determined following the guidance contained in ANSI/ANS 2.26.

TARGET DISPLACEMENT METHOD. A nonlinear static analysis procedure (described in FEMA 356) that provides a numerical process for estimating the displacement demand on the structure. A bilinear representation of the capacity curve and a series of modification factors, or coefficients, are used to calculate a target displacement. The point on the capacity curve at the target displacement is the equivalent of the performance point in the capacity spectrum method. See *Capacity Spectrum Method*.

TARGET PERFORMANCE GOAL (P_F). Target annual frequency of exceeding a specified Limit State. Performance goals of 1×10^{-4}, 4×10^{-5}, and

1×10^{-5} are established in this Standard for SDC-3, SDC-4, and SDC-5, respectively. For example, the expected probability of exceeding a Limit State in SDC-3 in any given year is less than 1/10,000. The user may specify, with justification, a unique value for a specific application.

UNIFORM HAZARD RESPONSE SPECTRA (UHRS). Response spectra derived so that the annual probability of exceeding the spectral quantity (acceleration, displacement, etc.) is the same for any spectral frequency. Determined in accordance with ANSI/ANS 2.27 and 2.29.

ZERO PACKING. The practice of lengthening the total duration of an earthquake accelerogram by adding values of zero acceleration to the beginning or the end of the record for the purpose of performing discrete Fourier analysis.

ZERO PERIOD ACCELERATION (ZPA). The maximum absolute value of the ground or in-structure acceleration time-history record.

Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities

SECTION 1.0 INTRODUCTION

SECTION 1.1 OVERVIEW OF THE SEISMIC DESIGN CRITERIA

This Standard provides criteria for seismic design of safety-related Structures, Systems, and Components (SSCs) in a broad spectrum of nuclear facilities. Notation, definitions, guidelines, and commentary material are included.

A graded approach is used in developing the seismic design criteria presented in this Standard. The intent is to control the design process such that the performance of the SSC related to safety and environmental protection is acceptable.

To implement the graded approach for seismic design, 20 Seismic Design Bases (SDBs) have been defined as specified in ANS 2.26 and as shown in Table 1-1. SDBs have a quantitative probabilistic Target Performance Goal, P_F, defined for each Seismic Design Category (SDC)* and a qualitative goal defined for each Limit State (LS) or level of acceptable structural behavior. SDBs defined by SDC 1 and 2 are covered by the approach presented in the International Building Code (IBC). In the future, the IBC will use ASCE 7 for its seismic criteria. This Standard, ASCE/SEI 43-05, presents design and analysis requirements for SDBs defined by SDC 3, 4, and 5 and all Limit States.

Target quantitative performance goals decrease in annual probability of exceeding acceptable behavior limits as the SDC increases from 1 to 5. Decreasing quantitative Target Performance Goals are achieved in this Standard by increasing seismic demand associated with the Design Basis Earthquake (DBE). The DBE is defined by Uniform Hazard Response Spectra (UHRS) determined at a specified annual probability of exceedance, H_D, multiplied by a Design Factor (DF). The UHRS annual probability of exceedance and the Design Factor are defined for each SDC in Section 2.0 of this Standard.

An SSC, when subjected to the DBE, has the greatest level of structural damage at Limit State A and the least level of structural damage at Limit State D. At Limit State A, large deformation and significant structural damage are acceptable. At Limit State D, no damage and essentially elastic behavior are the goal. Limit States B and C are at intermediate levels of acceptable structural damage. The levels of acceptable structural damage defined for each Limit State are achieved in this Standard by applying the appropriate inelastic energy absorption factor, F_μ, or the deformation limits as specified in Sections 5.0 and 8.0. These design provisions include specified levels of inelastic energy absorption, structural damping, structural capacity, and material strength. These design provisions also specify that seismic analyses are to conform to ASCE 4 and provide requirements for ductile detailing.

An integral part of the seismic design criteria given in the Standard are Quality Assurance (QA) measures and independent peer review. QA measures and the involvement of peer review are expected to take place throughout the design process, beginning with establishment of the DBE and continuing through the seismic analysis and the design and detailing tasks associated with final seismic design. QA measures and peer review, as addressed in Section 9.0 of this Standard, shall follow a graded approach with increasing rigor ranging from IBC Seismic Use Group III requirements for SDC-3 to nuclear power plant requirements for SDC-5.

The overall Seismic Design Procedure for SDC 3, 4, and 5 SSCs is shown in Figure 1-1. Table 1-2 summarizes recommended earthquake design provisions for these SDCs. Specific provisions are described in detail in Sections 2.0 through 9.0 of this Standard.

Design procedures specified in this Standard conform closely to common practices. The intended users of this Standard are the civil, mechanical, and structural engineers conducting the design of nuclear facilities.

* In this Standard, the term "Seismic Design Category" has a different meaning than in the International Building Code and ASCE 7.

SECTION 1.2 USE OF ASCE STANDARD 43-05 WITH OTHER CODES AND STANDARDS

This Standard provides criteria for seismic design of new nuclear facilities using the concept of SDBs defined by different SDCs and Limit States associated with a graded approach.

ANSI/ANS 2.26 provides criteria for selecting SDC and Limit State that establishes the SDB for each SSC at the facility. A numerical Target Performance Goal is associated with each SDC as specified in Table 1-3. Performance goals are expressed as the mean annual probability of exceedance of the specified Limit