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4-16

Seismic Analysis of Safety-Related Nuclear Structures

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DEDICATION

John D. Stevenson, Ph.D., P.E.
May 23, 1933–October 30, 2014

ASCE 4-16 is dedicated to Dr. John D. Stevenson: a leader in the nuclear energy industry for more than four decades, with seminal contributions in civil, structural, and mechanical engineering.

John Stevenson graduated with a bachelor of science degree from Virginia Military Institute (VMI) in 1954. After two years of service in the U.S. Army Corps of Engineers and six years of service on the faculty of VMI, he completed a master of science degree at Case Institute of Technology in 1962. Two years of research on nuclear weapons effects at the IIT Research Institute in Chicago followed, after which he began doctoral studies at Case Western University. He completed his Ph.D. at Case Western in 1968.

Between 1968 and 1981, John held senior positions with Westinghouse Electric Company, Case Western Reserve University, McKee and Company, and Woodward Clyde Consultants. In 1981, he founded Stevenson and Associates, a consulting engineering firm, which grew rapidly and had offices in Cleveland, Ohio; Boston, Massachusetts; Pilsen, Czech Republic; St. Petersburg, Russia; and Bucharest, Romania. He also served as a consulting engineer to the U.S. Nuclear Regulatory Commission, the Defense Nuclear Facility Safety Board, and the International Atomic Energy Agency.

John received many awards over his career, including the American Society of Civil Engineers (ASCE) Mosieff Award in 1971, the Civil Engineer of the Year in 1991 given by the Cleveland Section of the ASCE, the ASCE Stephen Bechtel Award in 1995, and the American Society of Mechanical Engineers (ASME) Bernard Langer Award in 1997.

A hallmark of John's career in the nuclear industry, which spanned more than 40 years, is his many important contributions to codes and standards for safety-related nuclear structures published by the American Concrete Institute, American Institute of Steel Construction, American Nuclear Society, American Society of Civil Engineers, and American Society of Mechanical Engineers: a broad spectrum of important contributions that collectively are likely unmatched in the nuclear industry in the United States.

John was an active member of the ASCE Committee on Dynamic Analysis of Nuclear Structures. He brought much to the committee, including a deep understanding of mechanical components and systems and ASME codes and standards. Frequently, he was the lone advocate for mechanical engineering systems in a roomful of civil and structural engineers. His efforts to extend ASCE Standards 4 and 43 to address mechanical components and systems greatly expanded the utility of these standards, which will be forever appreciated.

Through this dedication, the members of the ASCE 4 task committee acknowledge John's seminal contributions to the seismic engineering of safety-related nuclear structures. His absence from committee deliberations and vigorous discussions is, and will be, sadly missed.

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PREFACE

Nuclear facilities process, store, or handle radioactive materials in a form and quantity that pose a potential nuclear hazard to workers, the public, or the environment. Owing to the risk associated with such hazards, these facilities must comply with stringent government regulations. Ensuring that these facilities have a lower probability of unacceptable seismic performance than conventional facilities is also important.

This standard intends to provide criteria for seismic analysis such that the responses computed in accordance with this standard will have a small likelihood of being exceeded.

Four steps in the design and construction process lead to reliable nuclear safety-related structures under earthquake motions:

1. Definition of the seismic environment,
2. Analysis to obtain response information,
3. Design or evaluation of the various structural elements, and
4. Construction.

This standard provides requirements for performing Step 2. This standard may be used for analysis of either new or existing facilities.

This standard was developed with the intent that it would be used with ASCE/SEI 43, *Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities* (2005). When used with ASCE/SEI 43, this standard will produce a design that is associated with a target annual performance goal as described in ASCE/SEI 43.

Techniques other than those specified in this standard, including experience gained from past earthquakes, special analyses, and testing may also be used to determine the seismic response of structures, systems, or components (SSCs). However, such alternative methodologies shall be properly substantiated and shall conform to the intent of this standard.

This edition of the standard is an extensive update of ASCE 4-98. It incorporates recent developments in analysis procedures and the corresponding data reported in the literature. To aid the reader, the following briefly summarizes the revisions to the chapters and organization of this standard.

Chapter 1 defines the purpose and scope of the standard, use of this standard with other standards, and mandatory quality requirements.

Chapter 2 on seismic input has been rewritten and expanded to emphasize performance-based design motions in keeping with the guidance in ASCE/SEI 43 and using methodology from NUREG/CR-6728 (2001). It also includes a new section on probabilistic site response analysis.

Chapter 3 on modeling of structures is a new chapter that updates material from Section 3.1 of ASCE 4-98.

Chapter 4 on analysis of structures is a new chapter that covers the material that appears mostly in Section 3.2 of ASCE 4-98. Section 4.6 includes material on the multistep analysis of structures that appeared previously in Section 3.1.1.2 of ASCE 4-98. Chapter 4 also includes new material on nonlinear analysis of structures using the static method, the response-history method, and an approximate response-spectrum method.

Chapter 5 on soil-structure interaction modeling and analysis is a significant expansion and enhancement of the material in Section 3.3 of ASCE 4-98. Chapter 5 includes new material on developing performance-based seismic input motions for use in soil-structure interaction analyses that reflects the corresponding updates to Chapter 2. It also includes a new section on probabilistic soil-structure interaction analysis.

Chapter 6 is a new chapter devoted to input for subsystem analysis that updates and expands upon the material in Section 3.4 of ASCE 4-98. It includes new sections on probabilistic analysis of subsystems and a new section on the effect of wave incoherence on in-structure response spectra.

Chapters 7 through 12 are also new chapters dealing with special structures that require special treatment for seismic analysis owing to their unique or complex nature. Of the six new chapters, four are expanded versions of the provisions included in ASCE 4-98. The remaining two are new additions to the standard: distribution systems (Chapter 10) and sliding and uplift analysis of unanchored components (Chapter 11).

Chapter 7 includes detailed requirements for seismic analyses of buried piping and conduits. Both simplified and advanced analyses methods are addressed.

Chapter 8 addresses analyses of the parts of nuclear facilities that are below grade. These structures range from earth-retaining walls to walls of facilities that resist the seismic loads generated during a seismic event.

Chapter 9 updates the analyses methods for aboveground liquid storage tanks. These tanks may be constructed of steel or reinforced concrete, with or without a steel liner.

Chapter 10 discusses the analytical methods that are commonly used for seismic analysis of mechanical and electrical distribution systems. The components in this category include piping, conduits, ductwork, raceway systems, and supports for these components.

Chapter 11 considers analysis of unanchored components at nuclear facilities. This chapter provides simplified approaches that can be used in determining the seismic response of such components.

Chapter 12 contains special requirements for seismically isolated structures and components. It is greatly expanded from the brief version included in ASCE 4-98.

Appendix A is an update of evaluations beyond design basis in ASCE 4-98 and focuses on assessment of seismic vulnerabilities at nuclear facilities. It addresses identification of seismic vulnerabilities, quantification of risk or margin for new facilities, and evaluation of facilities for seismic events beyond the design basis.

Appendix B is a new addition to the standard and provides guidance for performing nonlinear three-dimensional time-domain soil-structure interaction analysis.

Attachments to Chapters 1, 10, and 11; commentaries to all chapters; and appendixes A and B are nonmandatory.

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In Memoriam: Dan Nuta

The Task Committee acknowledges the important contributions of Dan Nuta, an active committee member who brought reason to the standard. He was an acting structural engineer at the Indian Point Nuclear Generating Station and was responsible for implementation or review of many projects that used this standard. His good humor, his candor, and his contributions to the working group will be sorely missed.

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ABBREVIATIONS AND NOTATION

Abbreviations and Acronyms

ABS	absolute sum
ACI	American Concrete Institute
AISC	American Institute of Steel Construction
ANS	American Nuclear Society
ARS	acceleration response spectrum
ASCE/SEI	American Society of Civil Engineers / Structural Engineering Institute
ASME	American Society of Mechanical Engineers
ASTM	American Society of Testing and Materials
BDBE	beyond design basis earthquake
BE	best estimate
BNL	Brookhaven National Laboratory
CDF	cumulative distribution function; core damage frequency
CDFM	conservative deterministic failure margin
CEUS	central and eastern United States
COV	coefficient of variation
CQC	complete quadratic combination
CS	clearance to the stop
CSDRS	certified seismic design response spectra
DBE	design basis earthquake
D/C	demand-to-capacity ratio
DF	design factor
DOE	Department of Energy
DRM	domain reduction method
DRS	design response spectrum
EPRI	Electric Power Research Institute
ESAM	equivalent static analysis method
ESI	equipment-structure interaction
FA	fragility analysis
FFT	fast Fourier transform
FIRS	foundation input response spectra
FNA	fast nonlinear analysis
FP	friction pendulum
GMPE	ground motion prediction equation
HCLPF	high confidence of a low probability of failure
ISRS	in-structure response spectra
LB	lower bound
LCM	load coefficient method
LD	low damping
LDR	low-damping rubber
LHS	Latin hypercube simulation
LOCA	loss-of-coolant accident
LR	lead rubber
LRFD	Load and Resistance Factor Design
LVSSR	lateral-to-vertical-support-span ratio
MCS	Monte Carlo simulation
MDOF	multi-degree of freedom
MSE	mechanically stabilized earth
NEI	Nuclear Energy Institute
NEP	nonexceedance probability
NPP	nuclear power plant
NRC	Nuclear Regulatory Commission
NSSS	nuclear steam supply system
PBSRS	performance-based surface response spectra
PE	potential energy
PGA	peak ground acceleration
PGD	peak ground displacement
PGV	peak ground velocity
POD	proper orthogonal decomposition
PRA	probabilistic risk assessment
PSD	power spectral density
PSHA	probabilistic seismic hazards assessment
QA	quality assurance
RCTS	resonant column/torsional shear
RLE	review-level earthquake
RSMAM	response spectral modal analysis method
RVT	random vibration theory
SAM	seismic anchor motion
SCOR	soil column outcrop response
SDB	seismic design basis
SDC	seismic design category
SDOF	single degree of freedom
SIDRS	seismic isolation design response spectra
SMA	seismic margin assessment
SMACS	seismic methodology analysis chain and statistics
SPRA	seismic probabilistic risk assessment
SQUG	Seismic Qualification Utilities Group
SRSS	square-root-of-the-sum-of-squares
SSC	structure, system, and component
SSE	safe shutdown earthquake
SSI	soil-structure interaction
SSSI	structure-soil-structure interaction
UB	upper bound
UHRS	uniform hazard response spectrum
USNRC	United States Nuclear Regulatory Commission
V&V	validation and verification
WUS	western United States
ZPA	zero-period acceleration

Notation

α	end coefficient for the hanger; instability angle (Chapter 11); dynamic amplification factor;
α_i, β_i	proportional damping coefficients for the *i*th part of the structure;
α, β	proportional damping coefficients;
α_h	horizontal peak ground acceleration (*g*);
α_ε, α_κ	wave velocity coefficients;
$\alpha(\tau)$	acceleration time series;
$\alpha/2$	confidence level;
β	hysteretic damping; slope of back of wall to vertical;
β_D	seismic demand logarithmic standard deviation;
β_e	effective damping;
β_{eff}	equivalent viscous damping ratio;

β_f logarithmic standard deviation;
β_H damping ratio during full cycles of sliding displacements; logarithmic standard deviation;
β_N logarithmic standard deviation for the nonlinear factor;
β_p P-wave damping;
β_S strength logarithmic standard deviation; S-wave damping;
β_x, β_Ψ, β_z constants that are functions of the basemat dimensional ratio, L/B;
$\Gamma_{c\alpha}$ a row of secondary system participation factors, consisting of one term for each connecting degree of freedom;
Γ_j participation factor for *j*th mode;
Γ_{sj} participation factor for support *s*, *j*th mode;
γ shear strain; soil unit weight; coefficient defined in Chapter 11;
γ_{pw} plane wave coherency representing random horizontal spatial variation of ground motion;
$\gamma(\omega)$ coherency function;
δ maximum uplift at opposite end of the building; angle of wall friction;
δ_s best-estimate sliding displacement; sliding displacement;
Δ hanger displacement;
Δf_i total frequency variation;
$\Delta f_{0.8}$ total frequency range over spectral amplitudes that exceeds 80% of the peak spectral amplitude;
Δh longest side of an element in a finite element model;
$\Delta_{\max}$ maximum relative joint displacement; maximum positive horizontal displacement of an isolator;
$\Delta_{\min}$ minimum negative horizontal displacement of an isolator;
ΔP_{AE} dynamic soil pressure;
ΔT, Δt time step;
Δ_x^*, Δ_y^*, Δ_z^* translation components of input;
ε_{eff} effective shear strain;
ε_{ij} correlation coefficient for the *i*th and *j*th modes;
$(\varepsilon_a)_{\max}$ maximum axial strain;
θ rocking rotation angle; tangent angle for tank roof;
$\theta_{\max}$, θ_o, θ_{om} maximum joint rotation; maximum rocking angle;
θ_x^*, θ_y^*, θ_z^* rotational components of input;
$\ddot{\theta}$ rotational acceleration;
λ damping ratio for a material as a fraction of critical damping;
λ, λ_1, λ_2 damping values associated with spectral amplitudes S, S_1, *and* S_2;
λ_j damping ratio for the *j*th mode, expressed as a fraction of critical damping;
λ_k critical damping ratio of the *k*th mode of the subsystem;
$[\lambda K]_i$ stiffness matrix for the *i*th element or subsystem in the global coordinate system, scaled by the damping ratio of the *i*th element as a fraction of critical damping;
$[\lambda M]_i$ mass matrix for *i*th element or subsystem in the global coordinate system, scaled by the damping ratio of the *i*th element as a fraction of critical damping;
λ_w wavelength of the dominant seismic wave;
Λ_i modal mass ratio;
μ coefficient of friction; ductility ratio;
μ_d ductility demand;
μ_e effective coefficient of friction;
ν Poisson's ratio;
ν_c Poisson's ratio of concrete;
ν_s Poisson's ratio of steel;
ρ mass density;
ρ_{12} correlation coefficient between any two acceleration time series;
σ standard deviation;
σ_{ax} axial stress;
σ_{axial} maximum axial stress in tank wall;
σ_h, σ_{hoopmax} maximum hoop stress in tank wall;
σ_y effective yield stress;
σ_{vmmax} maximum von Mises stress in tank wall;
σ_2^0 lateral dynamic soil pressure against the retaining structure for $1.0g$ horizontal earthquake acceleration;
τ shear stress;
$\tau_{\max}$ maximum shear stress in tank wall;
ϕ angle of friction of soil; code-specified strength reduction factor;
ϕ_{ci}, $\{\phi_{ci}\}$ mode vector value from the primary system's modal displacement at the location of attachment of the secondary system;
$\{\phi_j\}$ shape of mode *j*;
$\{\phi_{s\alpha}\}$ αth normalized modal vector of the secondary system;
$[\phi]_i$ normalized mode-shape matrix of *i*th subsystem (fixed base);
$[\phi]$ mode-shape matrix;
φ_{max} upper bound for maximum curvature of the buried structure as a whole;
Ω_o seismic force amplification factor required to account for structural overstrength;
ω circular frequency (rad/s);
ω_e effective circular frequency;
$\overline{\omega}_j$ damped circular frequency of *j*th mode of the system;
ω_j undamped circular frequency of *j*th mode;
ω_k circular frequency of the *k*th mode of the subsystem (rad/s); frequency of interest;
$\omega_{\max}$ highest significant circular frequency of interest;
$\omega_{\min}$ lowest significant circular frequency of interest;
$\omega_{s\alpha}$ circular frequency of the *i*th uncoupled secondary system mode (rad/s);
ω_v vertical liquid circular natural frequency;
ω_2 fundamental circular frequency of the sloshing mode;
ξ separation distance between locations used in coherency function (m);
A area under the normalized seismic soil pressure curve; amplitude of the upward wave in a soil layer;
A_C soil contact area;
A_p cross-sectional area of the pipe;
A_g gross area of concrete section;
A_s gross area of reinforcing steel;
A_V peak vertical acceleration;
A_w area of web;
a acceleration; dynamic amplification factor; base-to-height ratio; peak acceleration of the ground motion;

$a_{\max}$ maximum ground acceleration;
a_1, a_2, a_3 coefficients used in coherency function;
B bandwidth-to-central-frequency ratio; width of the basemat perpendicular to the direction of horizontal excitation; amplitude of the downward wave in a soil layer; width of the base in the rocking direction;
B_Ψ coefficient used in equivalent rocking damping coefficient calculation;
b minimum horizontal distance from the edge of the body to center of gravity;
C seismically induced longitudinal compressive force per unit length in the tank shell;
C_I coefficient defined in Chapter 11;
C_{MRI} coefficient defined in Chapter 11;
C_R coefficient of restitution; coefficient defined in Chapter 11; rocking coefficient of restitution;
C_{STD} standard seismic capacity;
C_v coefficient that is a function of Poisson's ratio; coefficient of variation;
$[C]$ damping matrix;
$[C_{FB}]_i$ fixed-base damping matrix of ith subsystem;
$[C_H]$ effective damping force matrix due to velocity drag effects of water;
$[C_H^*]$ partitioned portion of effective damping force matrix due to velocity drag effects of water;
$[C]_i$ damping matrix for ith subsystem or part of structure;
$C_{1\%}$ coefficient defined in Chapter 1;
$C_{10\%}$ coefficient defined in Chapter 1;
$C_{50\%}$ median seismic capacity;
c apparent wave velocity; distance from neutral axis to outer extreme fiber;
c_s sliding coefficient;
c_t equivalent torsional damping coefficient;
c_x equivalent horizontal damping coefficient;
c_z equivalent vertical damping coefficient;
c_Ψ equivalent rocking damping coefficient;
D hysteric damping ratio; tank diameter;
$[D]_i$ diagonal matrix with $D_{kk} = 2\lambda_k M_k^* \omega_k = 2\lambda_k \omega_k$;
D_{BD} 90th percentile displacement for BDBE shaking at the plan center of mass of the isolated superstructure;
D_D 80th percentile displacement for DBE shaking at the plan center of mass of the isolated superstructure;
D_{STD} deterministic seismic demand defined in accordance with ASCE/SEI 43-05;
D_v coefficient that is a function of Poisson's ratio;
$D_{50\%}$ seismic demand for a specified DBE input; median seismic demand;
d displacement; peak displacement of the ground motion; liquid slosh height;
dt increment of the time signal;
E Young's modulus (modulus of elasticity);
E_B lateral beam stiffness;
E_c modulus of elasticity of concrete;
E_{DL} energy dissipated by viscous damping during a cycle of sliding;
EDC energy dissipated per cycle for an isolator;
E_{DS} energy dissipated during a cycle of sliding;
E_H elastic foundation stiffness;
E_s modulus of elasticity of steel;
E_{sct} secant modulus of elasticity;
E_l,E_u lower and upper bound values of modulus of elasticity of uncracked concrete;
E_x, E_y spring stiffnesses;
$E(t)$ cumulative energy of the acceleration time series;
F force resisted by longitudinal brace;
F_a axial force in buried structure;
F_r resultant force due to dynamic soil pressure acting on earth-retaining walls;
F_H correction for difference between the lateral inertial mass, M_L, and the vertical resisting mass, M; horizontal directionality factor;
F_{max}, F_{min} horizontal forces corresponding to Δ_{max} and Δ_{min} for an isolator, respectively;
$F_{N1\%}$ nominal factor of safety against 1% conditional probability of failure;
$F_{N10\%}$ nominal factor of safety against 10% conditional probability of failure;
F_{RS} resisting force to sliding;
F_V correction for probabilistically combined vertical ground motion; vertical directionality factor; maximum vertical response of the empty tank shell;
F_μ inelastic force reduction factor;
$F_{\mu STD}$ deterministic inelastic force reduction factor defined in accordance with ASCE/SEI 43-05;
$F_{\mu 50\%}$ median estimate of inelastic force reduction factor;
$F(\omega)$ Fourier amplitude of the acceleration time series computed of the duration t_m;
f friction force per unit length; fundamental frequency of fluid (Hz); ground motion frequency (Hz); longitudinal direction frequency;
f_1 parameter defined in Chapter 11;
f_c' specified compressive strength of concrete;
f_c central frequency for the frequencies that exceed 80% of the peak amplitude;
$f_c(\zeta)$ coefficient used in coherency function;
f_e effective rocking frequency;
$(f_e)_n$ natural frequency of the nth subsystem
f_{em} lowest natural frequency at which the horizontal input spectral acceleration demand, SAH_{DEM}, is maximum;
f_{es} lowest natural frequency at which the horizontal 10% damped vector spectral acceleration, SA_{VH}, equals c_s;
f_i frequency of ith mode of system; dominant fixed-base frequency for flexible structures;
f_j structural frequency at frequency j;
f_l frequency below which all modes are periodic;
$f_{\max}$ maximum friction force per unit length between the pipe and surrounding soil;
f_{Nyquist} Nyquist frequency;
f_s frequency of secondary system; piping fundament frequency; soil column frequency taken as $V_s/4H$;
f_r frequency above which all modes are rigid;
f_v frequency at which the peak spectral velocity occurs;
G shear modulus;
G_c shear modulus of reinforced concrete;
G_l, G_u lower and upper bound values of shear modulus of uncracked concrete;
G/G_o ratio of reduced shear modulus to original (low strain) shear modulus;

g	acceleration due to gravity;
H	story height; embedment depth (height); fluid height (ft); wall height below grade;
H_C	height to the center of resistance;
H_{CB}, H_{CT}	height to the bottom and top of the knuckle at the top of the tank cylinder;
H_{CE}	effective height of the intersection of the cylinder and fitted sphere;
H_F	height from the tank base to the top of the domed roof;
H_L	liquid depth;
H_{SC}	distance from tank base to roof for a flat-roofed tank;
h	center-of-gravity height; thickness of shell;
h_D	distance from the top of the spherical dome to its intersection with the cylinder;
h_L	height to center of gravity for the lateral inertial mass;
h_{sc}	freeboard (slosh height clearance);
I	importance factor;
I_o	total mass moment of inertia of structure and basemat about rocking axis at the base;
I_B	mass moment of inertia of the rigid body;
I_g	gross moment of inertia;
I_{post}	hanger bending moment of inertia;
I_t	polar mass moment of inertia of structure and basemat;
i	slope of ground surface behind retaining wall;
K	distributed mass of the piping system; load coefficient used in the seismic load coefficient method analysis; structural stiffness; liquid bulk modulus;
K_{AE}	active earth pressure coefficient with earthquake effect;
K_d	second-slope stiffness;
K_{hi}, K_v	load coefficients;
K_l	stiffness of longitudinal brace;
K_t	lateral stiffness of hanger; transverse bending stiffness of the hanger;
K^*	complex stiffness used in frequency-domain analyses;
$[K]$	stiffness matrix;
$[K_{cc}^s]$	a square matrix representing the stiff contribution of the secondary system to the stiffness matrix of the coupled primary-secondary system for the connecting degrees of freedom;
$[K]_i$	stiffness matrix for the ith part of the structure;
K_p	torsional rigidity;
K_u	elastic stiffness;
K_{xi}, K_{yi}	stiffnesses of ith wall or column, assuming rigid connection to floor, in x and y directions, respectively;
k_e	equivalent linear stiffness;
k_{eff}	equivalent horizontal stiffness of an isolator;
k_h	peak horizontal ground acceleration at the top of the wall (g);
k_R	approximate rotational stiffness;
k_o	initial stiffness;
k_s	secant stiffness reduction factor; secant stiffness;
k_t	unbraced hanger stiffness; equivalent torsional spring constant;
k_v	peak vertical ground acceleration at the top of the wall (g);
k_x, c_x	equivalent horizontal spring and damping constants;
$k_{x\psi}$	coefficient used in computation of center of resistance;
k_z, c_z	equivalent vertical spring and damping constants;
k_ψ, c_ψ	equivalent rocking spring and damping constants;
k_1, k_2	parameters defined in Section C3.6.2;
$k*$	complex wave number;
L	concentrated weight equivalent length of pipe; distance between the braced supports; length of basemat; half wavelength; distance between flexible joints of the long linear buried structure; length of cylinder; length of raceway segment; horizontal distance between two adjacent walls;
L_1	hanger height;
l_c	twice the distance from the top of the fluid to the center of the sloshing fluid mass (see Fig. 3-1);
l_h	maximum span between straight spans of pipe;
l_1	twice the distance from the bottom of the basin to the center of the impulsive fluid mass (see Fig. 3-1);
l_v	nominal deadweight spacing length;
l_1, l_2, l_3	pipe span lengths;
M	mass of the tray raceway supported by the hanger, or vertical resisting mass; mass of a structure or component; number of response parameters of interest; constrained modulus; vertical mass resisting rocking;
$[M]$	mass matrix;
$[M_H^*]$	partitioned effective (or added) mass matrix due to effects of water ($n \times n$);
$[M_H]$	effective (or added) mass matrix due to effects of water ($n \times n$);
$[M^*_{H12}]$	partitioned vector from the effective mass matrix that couples the submerged structure degrees of freedom with basin wall ($n \times 1$);
$[M_{H12}]$	vector for the effective mass matrix that couples the submerged structure's degrees of freedom with the basin wall ($n+1 \times 1$);
$[M]_i$	mass matrix for the ith part of the structure;
M_B	combined overturning moment at the tank base;
M_f	median value of the ratio of SA_{fi}/TSA_f
M_{ip}	in-plane moment;
M_L	lateral inertial mass;
$\{M_m\}$	vector of missing mass quantities at each degree of freedom ($n \times 1$);
M_{op}	out-of-plane moment;
M_{OT}	overturning moment;
$[M_p]$	mass matrix of the primary system;
M_{pi}	modal mass of primary structure for mode i;
M_r	resultant overturning moment about base of retaining structure for pressure distribution;
M_s	mass of substructure or subsystem; total mass of secondary system;
M_{s_i}	basin structure mass at node i;
M_1, M_2	parameters defined in Section C3.6.2; overturning moments caused by impulsive and sloshing modes excluding bottom pressure effects;
M_1, M_2, M_{11}, M_{12}, M_{22}	parameters defined in Section C3.6.2;

M'_1, M'_2 overturning moments caused by impulsive and sloshing modes including bottom pressure effects;
m mass per unit length of the raceway system; number of modes considered; ductility factor; meter; number of logarithmically spaced frequencies; total soil mass;
N number of hangers in the segment; number of modes considered in the analysis without missing mass; number of modes considered for the analysis; number of statistical response analysis simulations; number of probability bins; number of Monte Carlo simulations; number of points required for FFT analysis; number of simulated soil profiles; number of acceleration time series;
NF number of subsystem natural frequencies;
NS number of substructures being assembled;
n number of dynamic degrees of freedom or number of elements considered; number of acceleration points in a series; number of modes;
P axial load; mean of Gaussian distribution;
P_A active component of the overall soil pressure during a seismic event;
P_{AE} active soil pressure during the seismic event;
P_{base} pressure at the base of tank wall;
P_d dynamic pressure;
P_m maximum lateral seismic soil pressure;
P_s static pressure;
P_t total pressure;
P_v hydrodynamic pressure due to vertical motion;
P_1, P_2 hydrodynamic pressure caused by impulsive and sloshing modes; impulsive pressure and convective pressure in tank due to vertical excitation;
$\overline{\text{P}}$ nonexceedance probability;
$p(y)$ normalized soil pressure distribution;
Q generalized force;
Q_dW zero-displacement intercept;
Q_y yield force;
R length from base corner to center of gravity $= [\text{b}^2 + \text{h}^2]^{1/2}$; combined response due to the three orthogonal components of earthquake motion; radius of circular basemat; tank radius; total response of parameter of interest;
R_C overall median conservatism ratio associated with the acceptance criteria;
R_D median conservatism ratio associated with seismic demand defined in accordance with ASCE/SEI 43-05; spherical dome segment radius;
R_{Ii}, R_{Ij} response for the Ith component of motion; maximum probable response obtained by response-spectrum analysis of ith (jth) mode of vibration due to excitation of Ith direction (= 1, 2, 3);
R_i contribution to the response parameter of interest caused by the ith component of seismic input;
R_N median nonlinear factor ratio;
R_p response modification factor;
R_S median conservatism ratio associated with component strength defined in accordance with ASCE/SEI 43-05;
$R(t)$ combined response time history;
$R(\omega)$ response in the frequency domain;
r reduction in rotational velocity during one cycle of response; horizontal radius of the roof;
r_{ia} modal mass ratio for primary system mode i and secondary system mode a;
r_K knuckle radius;
S code-allowed normal stress;
S, S_1, S_2 spectral amplitudes associated with damping values λ, λ_1, and λ_2;
S_a, SA spectral acceleration;
$S_a(f)$ spectral acceleration value applicable at the base of the raceway support at frequency f;
$S_a(f_s, 30\%)$ acceleration spectral value of the free-field response at the soil column frequency obtained at the depth of the bottom of the wall in terms of acceleration response spectrum at 30% damping;
SA_{fi}/TSA_{fi} ratio of spectral acceleration of conditioned record to the target spectral acceleration at frequency f_i;
SAH_{CAP} horizontal spectral acceleration capacity;
SAH_{DEM} horizontal input spectral acceleration demand;
$SAH_{DEM,E}$ horizontal input spectral acceleration demand at the elastic frequency and elastic damping;
SA, SA_H, SA_V spectral accelerations;
SA_{H_1}, SA_{H_2} 10%-damped spectral accelerations for each of the two orthogonal horizontal components;
S_{all} longitudinal stress in the pipe due to other than seismic inertia load;
$S_{A\max}$ highest spectral acceleration in the interval between the highest target frequency and the frequency at the ZPA;
SA_{VH} horizontal 10%-damped vector spectral acceleration;
$SA_{VH,E}$ vector horizontal spectral acceleration demand at the elastic frequency;
S_{a_v} vertical spectral acceleration of the tank base at the vertical liquid response mode natural frequency;
S_{a1} spectral acceleration at the fundamental impulsive mode;
S_{a2} spectral acceleration at the fundamental sloshing mode;
$S_{ii}(\omega)$,$S_{jj}(\omega)$ auto PSD functions of the motions at locations i and j;
$S_{ij}(\omega)$ cross-PSD between the motions at locations i and j;
SF_{yield} safety factor against yield in tank wall;
S_m stress intensity;
S_p maximum longitudinal pressure stress;
S_{peak} peak spectral acceleration in gravity unit from the DRS or ISRS;
S_{STD} deterministic estimate of component strength defined in accordance with ASCE/SEI 43-05;
S_t code allowable stress when design basis seismic inertia stresses are included;
S_u specified minimum ultimate stress;
S_v spectral velocity;
S_y specified minimum yield stress;
$S_{v\max}$ maximum spectral velocity;
$S(f, \lambda)$ response spectra (function of frequency and damping);
$S(\omega)$ one-sided PSD;

$S_{50\%}$ median estimate of component strength;
s second;
$T(\omega)$ transfer function for the structure at circular frequency ω;
$T(\omega_\kappa)$ transfer function for the structure at circular frequency of interest ω_k;
$[T_r]_i$ connectivity matrix between the rigid-body motions about the base coordinates and the free degrees of freedom of the subsystem;
t time; cylindrical tank wall thickness;
t_m equivalent strong motion duration;
$\{U_b\}$ vector indicating direction of ground acceleration with respect to global coordinates;
$\{U_o^*\}$ foundation input motion;
$\{U_{sc}\}$ secondary system influence matrix consisting of one influence vector for each connecting degree of freedom, c. The influence vector for a connecting degree of freedom is the displacement vector of the secondary system when the particular degree of freedom undergoes a unit displacement;
u displacement;
$\ddot{u}_g$ ground or base acceleration;
$\ddot{u}_g(\omega)$ Fourier transform of the ground acceleration time history; $\ddot{u}_g(t)$;
$\{\ddot{u}_g\}$ basin acceleration time history;
u_y yield displacement for LR and FP bearings;
V wall shear; static equivalent load (force); peak ground velocity;
V_c nominal concrete shear capacity; compressive wave velocity (ft/s)
V_p compression wave velocity; coefficient of variation;
V_s shear wave velocity; average shear wave velocity of the soil column over the embedment height of the wall;
V/H ratio of vertical to horizontal spectral response;
v peak velocity of the ground motion;
v_{max} maximum ground velocity;
W actual width of flange; weight of SSC, or total hanger weight; effective seismic weight of the SSC; weight of wedge; reactive weight of the structure above the isolation surface;
W_c concentrated weight on pipe span;
W_e effective flange width;
W_p unit weight of pipe;
W_s tank shell weight;
W_T total liquid weight;
W_1, W_2 effective liquid impulsive and sloshing weights;
w_c unit weight of concrete;
X,Y two acceleration time series;
$\{X\}$ relative displacement vector;
$\{\dot{X}\}$ relative velocity vector;
$\{\ddot{X}\}$ relative acceleration vector;
$\overline{X}_i$, $\overline{Y}_i$ coordinates of ith wall or column elements;
X_{cr}, Y_{cr} coordinates of center of rigidity;
X_s height to the centroid of the tank shell;
$\{X_o\}$, $\{X_o(max)\}$ residual rigid response;
X_1, X_2 height above the base of the tank to the centroid of the impulsive and sloshing weights neglecting bottom pressure effects;
X_1', X_2' height above the base to the centroid of impulsive and sloshing weights including bottom pressure effects;
x width of the basemat in contact with the soil; horizontal axis;
x_1, x_2 parameters defined in Section C3.6.2;
$\ddot{x}$, $\ddot{y}$ horizontal and vertical input accelerations;
$\{Y\}$ vector of normal, or generalized, coordinates $(m \times 1)$;
Y_j generalized coordinate of the ith mode;
Y_r point of application for the resultant force;
y depth from top of fluid; normalized height ratio; horizontal axis;
Y distance from base of retaining structure;
z depth within a soil layer;
$z_{\alpha/2}$ number of standard deviations that corresponds to the confidence level of $\alpha/2$

DEFINITIONS

The following terms are defined for general use in this standard.

ACCELERATION TIME SERIES: A sequence of acceleration and time data pairs, typically representing the acceleration response in a single direction during an earthquake. (Informally known as a time history.)

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

APPARENT WAVE PROPAGATION VELOCITY: The apparent propagation velocity of seismic waves through the ground relative to a fixed local coordinate system.

BASEMAT: In the context of seismically isolated structures, the basemat is a thick reinforced concrete diaphragm immediately above the isolation system.

CLEARANCE TO THE STOP: The maximum horizontal distance between the superstructure of a seismically isolated structure and the stop, which can be no less than the 90th percentile displacement for 150% DBE shaking.

COMPETENT SOIL: Any natural or improved soil that has a low-strain shear wave velocity, V_s >1,000 ft/s (300 m/s).

COUPLED: A descriptive term for mathematical models of structures and components that are interconnected and, because of their coupling, influence the dynamic response of each other.

CUTOFF FREQUENCY: The highest frequency used in the dynamic analysis of the structure or the soil-structure system.

DESIGN BASIS EARTHQUAKE (DBE): The description of the ground motion, defined in terms of the DRS, to be used for design.

DESIGN (OR EVALUATION) GROUND ACCELERATION: The value of the acceleration that corresponds to acceleration at zero period in the design ground-response spectrum.

DESIGN (OR EVALUATION) RESPONSE SPECTRUM (DRS): A smooth response spectrum of the input motion at the foundation level that can be used for either design or evaluation.

DISTRIBUTION SYSTEM: 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 FREQUENCY: The frequency associated with maximum modal mass in each direction. Frequencies having a modal mass equal to 20% or more of the total structural mass are considered dominant.

DOMINANT RESPONSE PARAMETER: The response mode of the structural component with 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].

DOMINANT SEISMIC WAVE (P, S, Love, Rayleigh): The type of seismic wave that dominates the local site response. The dominant seismic wave is site dependent.

DYNAMIC LATERAL EARTH PRESSURE: Lateral soil pressure induced by dynamic movements of the soil and structure (such as earthquakes); dynamic soil pressure can be either active or passive.

EQUIVALENT HORIZONTAL STIFFNESS: The value of the lateral force in a seismic isolation system, or an element thereof, divided by the corresponding lateral displacement; also termed secant stiffness.

EQUIVALENT VISCOUS DAMPING RATIO: The value of equivalent viscous damping corresponding to energy dissipated during cyclic response of a seismic isolation system.

FINISHED GRADE: The top of the ground surface at a site after cut or fill operations have been completed.

FOUNDATION: In the context of a seismically isolated structure, a foundation is a reinforced concrete foundation, including pedestals, that supports the isolators.

FREE FIELD: As used in soil-structure interaction analysis, the free-field response (acceleration, velocity, displacement) is the site response in the absence of structure.

FREE-FIELD GROUND SURFACE: Ground surface that is sufficiently distant from the site to be essentially unaffected by the vibration of site structures.

GEOMETRIC MEAN: An averaged horizontal spectral acceleration calculated frequency by frequency as the square root of the product of the spectral accelerations along orthogonal axes.

GRADED APPROACH: A process by which the level of analysis, documentation, and actions necessary to comply with requirements are commensurate with

- The relative importance to safety, safeguards, and security and of radiological and nonradiological hazards;
- The magnitude of any hazard involved;
- The life cycle stage of a facility;
- The programmatic mission of a facility;
- The particular characteristics of a facility; and
- Any other relevant factor.

GROUND MOTION HISTORY: A set of three orthogonal acceleration time series, typically two horizontal and one vertical, that represents the acceleration response of the ground during an earthquake. A ground motion history may be defined at the surface or at depth.

HIGHEST TARGET FREQUENCY: The highest frequency in the frequency range of interest that must be adequately represented in the dynamic solution of the structure or the soil-structure system.

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

ISOLATION INTERFACE: In the context of seismically isolated structures, the isolation interface is the interface between the isolated superstructure and the supporting (nonisolated) foundation.

ISOLATION SYSTEM: In the context of a seismically isolated structure, the isolation system is the collection of structural elements that includes all individual isolator units, all structural elements that transfer force between elements of the isolation system, and all connections to other structural elements. The isolation system also includes structural elements that provide restraint of the seismic-isolated structure for wind loads.

ISOLATION SYSTEM EFFECTIVE DAMPING: In the context of seismic isolation systems, the isolation system effective damping is the equivalent viscous damping based on isolator hysteretic damping and corresponds to the energy dissipated during cyclic response of the isolation system. Such isolators are modeled with a linear spring and dashpot.

ISOLATOR UNIT: In the context of seismic isolation systems, an isolator unit is a horizontally flexible and vertically stiff structural element of the isolation system that permits large lateral deformations under design seismic load. An isolator unit may be used either as part of, or in addition to, the weight-supporting system of the structure.

LATERAL ACTIVE EARTH PRESSURE: Soil pressure that may be exerted by the soil that is in extension. The limiting active soil pressure is such that the soil expands outward to the point of reaching the limiting strength (shear failure) of the soil in extension. It represents the minimum lateral soil pressure.

LATERAL AT-REST EARTH PRESSURE: Soil pressure that may be exerted in a horizontal plane by the in situ soil that is not subject to either extension or compression.

LATERAL PASSIVE EARTH PRESSURE: Lateral soil pressure that may be exerted by the soil that is externally forced into compression. The limiting passive soil pressure is such that the soil is externally forced to the limiting strength (shear failure) of the soil in compression. It represents the maximum lateral soil pressure.

LICENSED PROFESSIONAL ENGINEER: An individual who is registered or licensed to practice his/her respective engineering profession as defined by the statutory requirements of the professional registration laws of the state or other governing body having jurisdictional authority.

LIMIT STATE (LS): The limiting acceptable condition of the structure, system, or component. The limit state may be defined in terms of a maximum acceptable displacement, strain, ductility, or stress. Four limit states are defined in ASCE 43-05 for nuclear safety-related SSCs.

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.

MOAT or ISOLATION GAP: In the context of a seismically isolated structure, the moat or isolation gap is the width around the perimeter of the isolated superstructure in which the superstructure can move without restriction. The width is defined by the clearance to the hard stop.

MULTISTEP METHOD: A method of structural analysis that involves calculating intermediate results in the first step and using these results as input to subsequent steps.

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; and/or
- 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.

NUCLEAR FACILITY: Includes both reactor and nonreactor facilities.

ONE-STEP METHOD: In contrast to the previously defined multistep method, the one-step method is a method of structural analysis that is a single, self-contained analytical technique.

PEAK GROUND ACCELERATION (PGA): The maximum absolute value of a component of accelerogram history.

PEAK SPECTRAL ACCELERATION: The peak acceleration in an acceleration response spectrum.

PEER REVIEW: A formal review process in which an external party reviews the methodology, results, and process by which a design is developed or an evaluation is carried out. The external party shall be independent of project schedule and budget constraints.

PERFORMANCE-BASED DESIGN MOTIONS: Seismic motions (e.g., response spectra, ground motion histories, etc.) developed through probabilistic methods with the intent of providing a level of seismic input consistent with a performance goal.

RIGID: A descriptive term for structures or components whose fundamental frequency is equal to or greater than the rigid (ZPA) frequency.

RIGID FREQUENCY: The lowest frequency at which the spectral acceleration becomes practically independent of frequency and damping (and is approximately equal to the ZPA).

SEISMIC DEMAND: The demand imposed on the structure, system, or component 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 seismic design category (1, 2, 3, 4, or 5) and limit state (A, B, C, or D) that determines the design basis earthquake and acceptance criteria for designing SSCs. For example, Seismic Design Basis 3C would use criteria given in this standard for Seismic Design Category 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 seismic design categories 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 Seismic Design Category 1; a safety-related SSC in a nuclear-material-processing facility with a large inventory of radioactive material may be placed in Seismic Design Category 5. In this standard, the term *seismic design category* has a different meaning than it has in the International Building Code.

SIGNIFICANT: As used in this document, the term *significant* involves the use of engineering judgment, but a general rule is that when a quantitative response goal is met within 10%, the difference is not significant.

SPECTRA: Various definitions of spectra are used in soil-structure interaction and structural response analyses. These include

- **CERTIFIED SEISMIC DESIGN RESPONSE SPECTRA (CSDRS):** For standard nuclear power plants, CSDRS are site-independent seismic design response spectra that have been approved under Subpart B, "Standard Design Certifications," of Title 10, Part 52, "Early Site Permits: Standard Design Certifications; and Combined Licenses for

Nuclear Power Plants," of the Code of Federal Regulations (10 CFR Part 52) as the seismic design response spectra for certified standard design nuclear power plants. CSDRS are used for design of the standard power plants for a range of soil profiles adopted for the generic design.

- **FOUNDATION INPUT RESPONSE SPECTRA (FIRS):** FIRS are the site-specific performance-based design response spectra characterized by horizontal and vertical spectra at the foundation level of the structure in the free field. For some nuclear structures, a minimum requirement for FIRS must be maintained. Development of FIRS shall be consistent with Chapters 2 and 5 of this standard, and the SSI modeling must account for the soil properties beneath and around the structures.
- **PERFORMANCE-BASED SURFACE RESPONSE SPECTRUM:** A site-specific performance-based response spectrum defined at the free surface and developed using probabilistic procedures similar to the development of FIRS.

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.

STOP: In the context of a seismically isolated structure, a stop is a structure, or series of structures, designed to prevent excessive displacement of the isolation system. A moat wall could serve as a hard stop.

STRUCTURE, SYSTEM, AND 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.

SUPERSTRUCTURE: In the context of a seismically isolated structure, the superstructure is composed of all structural elements above the isolation system (e.g., slabs, beams, columns, and walls). For a conventional light-water reactor, the structural framing includes primary and secondary containment, internal structure to support the power generation and safety-related components and systems, and the basemat (or diaphragm) immediately above the isolation system.

UMBILICALS: In the context of seismically isolated structures, umbilical lines are nonstructural components and systems, mainly distribution systems, that cross the isolation interface and sustain the large isolator displacements (or deformations) associated with design basis and beyond design basis earthquake shaking. Examples of umbilical lines could include high-pressure steam lines from the power reactor to the turbines and cables located on trays or in ducts from emergency power systems located off the nuclear island to the power reactor.

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.

WAVE INCOHERENCY: A term describing variation of horizontal and vertical ground motion due to differential arrival time of the seismic waves and heterogeneous nature of the medium beneath the foundation.

ZERO-PERIOD ACCELERATION (ZPA): The response-spectrum acceleration in the rigid range of the spectrum, typically at and above 33 Hz, which is equal to the maximum absolute value of the corresponding acceleration time series.

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CHAPTER 1
GENERAL

1.1 INTRODUCTION

1.1.1 Purpose. This standard provides minimum requirements and acceptable methods for the seismic analyses of safety-related structures of a nuclear facility. The standard provides methods for calculating seismic responses in structures and for deriving input motions for use in the seismic design and qualification of electrical and mechanical systems and components.

The purpose of the analytical methods is to provide reasonable levels of conservatism to account for uncertainties. The following areas for deterministic seismic analyses contain conservatism:

1. The spectra of acceleration histories used in analysis envelop the design response spectra, thus introducing some level of conservatism.
2. For soil-structure interaction, a minimum of three soil cases are analyzed using a range of soil properties, and the results are enveloped.
3. For in-structure response spectra, the peaks are broadened.
4. For structural damping, generally conservative values are specified.
5. The use of response-spectrum analysis and equivalent static methods generally results in conservative demand estimates.

For certain special structures covered in Chapters 7–12 of this standard, added conservative assumptions are incorporated into the analysis process to account for highly variable physical properties and analysis parameters. The goal of the added conservatism is to preclude underestimation of response that may lead to unacceptable behavior.

Given the seismic design response spectra, the goal of the standard is to develop seismic responses with 80% probability of nonexceedance. For probabilistic seismic analyses, the response with 80% probability of nonexceedance is selected.

1.1.2 Scope

1.1.2.1 Types of Structures Covered by This Standard. This standard is intended for use in the seismic analysis of all safety-related structures of nuclear facilities, including but not limited to above- and below-ground structures, buried piping, vertical liquid storage tanks, distribution systems, anchored and unanchored components, and structures with seismic isolation systems. Analysis of caisson and pile-supported foundations, unlined tunnels, and floating structures are not covered by this standard. However, nothing in this standard precludes the use of these structures and structural elements.

1.1.2.2 Foundation Material Stability. The analysis procedures provided herein assume that the foundation media adequately support the structures analyzed and that no soil or rock failure occurs that would modify or void the seismic analysis.

1.1.3 General Requirements

1.1.3.1 Use of Analysis Results. The seismic responses determined from the analysis prescribed herein shall be combined with responses due to nonseismic loads.

1.1.3.2 Use of ASCE 4 with Other Codes and Standards. This standard provides criteria for determining the response of structural elements in new facilities when subjected to earthquake ground motion. The standard is to be used in conjunction with other national consensus standards for producing reliable structural, system, and component designs. ASCE/SEI 43 (ASCE 2005), "Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities," presents design criteria for new nuclear facilities using the concept of seismic design bases (SDBs) defined by different seismic design categories (SDCs) and limit states associated with a graded approach. The SDC is used to set the design earthquake levels. The limit state is used to set the analysis methodology, design procedures, and acceptance criteria.

ANSI/ANS 2.26 (ANSI/ANS 2004; R2010), "Categorization of Nuclear Facility Structures, Systems, and Components for Seismic Design" and associated standards ANSI/ANS 2.27 (ANSI/ANS 2008b), "Site Characterization Requirements for Natural Phenomena Hazards at Nuclear Facilities Sites," and ANSI/ANS 2.29 (ANSI/ANS 2008a), "Probabilistic Analysis of Natural Phenomena Hazards at Nuclear Facilities Sites," provide criteria for selecting the SDC and limit state that establish the SDB for each structure, system, and component (SSC) at the facility. A numerical target performance goal is associated with each SDC. Performance goals are expressed as the mean annual probability of exceedance of the specified limit state of structures and equipment. The deformation limits associated with each limit state are prescribed in ASCE/SEI 43 (ASCE 2005).

1.1.3.3 Alternative Methodologies. Techniques other than those specified in this standard, including experience gained from earthquakes, special analyses, and testing, may be used in lieu of the requirements specified herein. These methods must be shown to provide seismic design input to the SSCs that is at the 80% nonexceedance level. Alternative methodologies shall be properly substantiated.

1.2 SEISMIC QUALITY PROVISIONS

The seismic analysis of nuclear structures covered by this standard will be performed under the purview of the U.S. Department of Energy (DOE) or the U.S. Nuclear Regulatory Commission (USNRC). The DOE and USNRC have regulatory quality assurance (QA) requirements that are applicable throughout the design activities, including seismic analysis. Verification