Chapter 14

NONBUILDING STRUCTURE DESIGN REQUIREMENTS

14.1 GENERAL:

14.1.1 Scope: *Nonbuilding structures* considered by the *Provisions* include all self-supporting *structures* which carry *gravity loads*, with the exception of: *buildings*, vehicular and railroad bridges, nuclear power generation plants, offshore platforms, and dams. *Nonbuilding structures* are supported by the earth or supported by other *structures*, and shall be designed and detailed to resist the minimum lateral forces specified in this chapter . Design shall conform to the applicable requirements of the *Provisions* as modified by this chapter. Nonbuilding structures that are beyond the scope of this section shall be designed in accordance with approved standards. Approved standards as referenced herein shall consist of standards approved by the authority having jurisdiction and shall be applicable to the specific type of nonbuilding structure.

The design of *nonbuilding structures* shall provide sufficient stiffness, strength, and ductility, consistent with the requirements specified herein for buildings, to resist the effects of seismic ground motions as represented by the following:

a. Applicable strength and other design criteria shall be obtained from other sections of the *Provisions* or its referenced codes and standards.

b. When applicable strength and other design criteria are not contained in or referenced by the *Provisions*, such criteria shall be obtained from approved standards. Where approved standards define acceptance criteria in terms of allowable stresses as opposed to strength, the design *seismic forces* shall be obtained from the *Provisions* and reduced by a factor of 1.4 for use with allowable stresses. Allowable stress increases used in approved standards are permitted. Detailing shall be in accordance with the approved standards.

14.2 REFERENCES:

ACI 313	American Concrete Institute (ACI), *Standard Practice for the Design and Construction of Concrete Silos and Stacking Tubes for Storing Granular Materials*, ACI 313, 1997
ACI 350.3	American Concrete Institute (ACI), *Standard Practice for the Seismic Design of Liquid-Containing Concrete Structures*, ACI 350.3/350.3R, 2001
ACI 371R-98	American Concrete Institute (ACI), *Guide to the Analysis, Design, and Construction of Concrete-Pedestal Water Towers*, ACI 371R, 1995
ANSI K61.1	American National Standards Institute (ANSI), *Safety Requirements for the Storage and Handling of Anhydrous Ammonia*, ANSI K61.1

ANSI/API 620	American Petroleum Institute (API), *Design and Construction of Large, Welded, Low Pressure Storage Tanks*, API 620, 1992
ANSI/API 650	American Petroleum Institute (API), Welded Steel Tanks For Oil Storage, API 650, 10th Edition, November 1998.
ANSI/API 653	American Petroleum Institute (API), *Tank Inspection, Repair, Alteration, and Reconstruction*, API 653, 2nd edition, December 1995
ANSI/API 2510	American Petroleum Institute (API), *Design and Construction of Liquefied Petroleum Gas Installation*, ANSI/API 2510, 7th Edition, May 1995
API Spec 12B	American Petroleum Institute (API), *Bolted Tanks for Storage of Production Liquids*, Specification 12B, 14th edition, February 1995
ASCE Task Rpt	American Society of Civil Engineers (ASCE) Petrochemical Energy Committee Task Report, *Design of Secondary Containment in Petrochemical Facilities*, 1997
ASCE 7	American Society of Civil Engineers (ASCE), *Minimum Design Loads for Buildings and Other Structures*, ASCE 7, 1998
ASME BVP	American Society of Mechanical Engineers (ASME), *Boiler And Pressure Vessel Code*, including addenda through 1998
ANSI/ASME	American Society of Mechanical Engineers (ASME), STS-1*Steel Stacks*, ASME STS, 1992
ASME B31.8	American Society of Mechanical Engineers (ASME), *Gas Transmission and Distribution Piping Systems*, ASTM B31.8, 1995
ASME B96.1	American Society of Mechanical Engineers (ASME), *Welded Aluminum-Alloy Storage Tanks*, ASME B96.1, 1993
ASTM F1159	American Society for Testing and Materials (ASTM), *Standard Practice for the Design and Manufacture of Amusement Rides and Devices*, ASTM F1159, 1992
ASTM C 1298	American Society of Testing and Materials (ASTM), *Standard Guide for Design and Construction of Brick Liners for Industrial Chimneys*. (ASTM C1298)
ANSI/AWWA D100 D5.2	American Water Works Association (AWWA), *Welded Steel Tanks AWS forWater Storage*, 1996
ANSI/AWWA D103	American Water Works Association (AWWA), *Factory-Coated Bolted Steel Tanks for Water Storage*, 1997
ANSI/AWWA D110	American Water Works Association AWWA), *Wire- and Strand-Wound Circular for Water Storage*, 1995
ANSI/AWWA D115	American Water Works Association (AWWA), *Circular Prestressed Concrete Tanks with Circumferential Tendons*, 1995

ANSI/NFPA 30	National Fire Protection Association (NFPA), *Flammable and Combustible Liquids Code*, 1996
ANSI/NFPA 58	National Fire Protection Association (NFPA), *Storage and Handling of Liquefied Petroleum Gas*, 1995
ANSI/NFPA 59	National Fire Protection Association (NFPA), *Storage and Handling of Liquefied Petroleum Gases at Utility Gas Plants*, 1998
ANSI/NFPA 59A	National Fire Protection Association (NFPA), *Production, Storage and Handling of Liquefied Natural Gas (LNG)*, 1996
RMI Specification	Rack Manufacturers Institute (RMI), *Specification for the Design, Testing, and Utilization of Industrial Steel Storage Racks*, 1997
Troitsky 1990	Troitsky, M. S., *Tubular Steel Structures*, 1990
49CFR, Part 193	U.S. Department of Transportation (DOT), *Pipeline Safety Regulations*, Title 49 CFR Part 193
NAVFAC R-939	U.S. Naval Facilities Command (NAVFAC), *The Seismic Design of Waterfront Retaining Structures*, NAVFAC R-939
NAVFAC DM-25.1	U.S. Naval Facilities Engineering Command (NAVFAC), *Piers and Wharves*. NAVFAC DM-25.1
Army TM 5-809-10/ NAVFAC P-355/ Air Force AFM 88-3	U.S. Army Corps of Engineers (USACE), *Seismic Design for Buildings* Chapter 13, 1992

14.3 INDUSTRY DESIGN STANDARDS AND RECOMMENDED PRACTICE: The following standards and references form a part of the *Provisions* as referenced herein.

TABLE 14.3 Standards, Industry Standards, and References

Application	Standard or Reference
Steel *Storage Racks*	RMI Specification
Piers and Wharves	NAVFAC R-939, NAVFAC DM-25.1
Welded Steel Tanks for Water Storage	AWWA D100
Welded Steel Tanks for Petroleum and Petrochemical Storage	API 650, API 620
Bolted Steel Tanks for Water Storage	AWWA D103
Concrete Tanks for Water Storage	AWWA D115, AWWA D110, ACI 350.3
Pressure Vessels	ASME
Refrigerated Liquids Storage:	
Liquid Oxygen, Nitrogen and Argon	NFPA 50
Liquefied Natural Gas (LNG)	NFPA 59A, DOT 49CFR
LPG (Propane, Butane, etc.)	NFPA 59, API 2510
Ammonia	ANSI K61.1
Concrete silos and stacking tubes	ACI 313
Petrochemical *structures*	ASCE Design of Secondary Containment

Application	Standard or Reference
	in Petrochemical Facilities
Impoundment dikes and *walls*:	
Hazardous Materials	ANSI K61.1
Flammable Materials	NFPA 30
Liquefied Natural Gas	NFPA 59A, DOT 49CFR
Cast-in-place concrete stacks and chimneys	ACI 307
Steel stacks and chimneys	ASME STS
Guyed steel stacks and chimneys	ASME STS, Troitsky 1990
Brick masonry liners for stacks and chimneys	ASTM C1298
Amusement *structures*	ASTM F1159

14.4 NONBUILDING STRUCTURES SUPPORTED BY OTHER STRUCTURES: If a *nonbuilding structure* is supported above the *base* by another *structure* and the weight of the *nonbuilding structure* is less than 25 percent of the combined weight of the *nonbuilding structure* and the supporting *structure*, the design *seismic forces* of the supported *nonbuilding structure* shall be determined in accordance with the requirements of Sec. 6.1.3.

If the weight of a *nonbuilding structure* is 25 percent or more of the combined weight of the *nonbuilding structure* and the supporting *structure*, the design *seismic forces* of the *nonbuilding structure* shall be determined based on the combined *nonbuilding structure* and supporting structural system. For supported *nonbuilding structures* that have non-rigid *component* dynamic characteristics, the combined system R factor shall be a maximum of 3. For supported *nonbuilding structures* that have rigid *component* dynamic characteristics (as defined in Sec. 14.2.2), the combined system R factor shall be the value of the supporting structural system. The supported *nonbuilding structure* and *attachments* shall be designed for the forces determined for the *nonbuilding structure* in a combined systems analysis.

14.4.1 Architectural, Mechanical, and Electrical Components: Architectural, mechanical, and electrical *components* supported by *nonbuilding structures* shall be designed in accordance with Chapter 6 of the *Provisions*.

14.5 STRUCTURAL DESIGN REQUIREMENTS:

14.5.1 Design Basis: *Nonbuilding structures* having specific seismic design criteria established in approved standards shall be designed using the standards as amended herein. In addition, *nonbuilding structures* shall be designed in compliance with Sec. 14.3 and 14.4 to resist minimum seismic lateral forces that are not less than the requirements of Sec. 5.4.1 with the following additions and exceptions:

1. The response modification coefficient, R, shall be the lesser of the values given in Table 14.5.1.1 or the values in Table 5.2.2.
2. For nonbuilding systems that have an R value provided in Table 14.5.2.1, the minimum specified value in Eq. 5.4.1.1-1 shall be replaced by:

$$C_s = 0.14 S_{DS} I \qquad (14.2.1\text{-}1)$$

and the minimum value specified in Eq. 5.3.2.1-4 shall be replaced by:

$$C_s = 0.8 S_1 I / R \qquad (14.2.1\text{-}2)$$

3. The overstrength factor, Ω_0, shall be as given in Table 14.5.1.1 or Table 5.2.2..
4. The importance factor, I, shall be as given in Table 14.5.1.2 .
5. The height limitations shall be as given in Table 14.5.1.1 or Table 5.2.2.
6. The vertical distribution of the lateral *seismic forces* in *nonbuilding structures* covered by this section shall be determined:
   a. In accordance with the requirements of Sec. 5.4.3 or
   b. In accordance with the procedures of Sec. 5.5 or
   c. In accordance with an approved standard applicable to the specific *nonbuilding structure*.
7. For nonbuilding structural systems containing liquids, gases, and granular solids supported at the base as defined in Sec. 14.7.3.1, the minimum seismic design force shall not be less than that required by the approved standard for the specific system.
8. Irregular *structures* per Sec. 5.2.3 at sites where the seismic coefficient S_{DS} is greater than or equal to 0.50 that cannot be modeled as a single mass shall use the procedures of Sec. 5.5.
9. Where an approved standard provides a basis for the earthquake resistant design of a particular type of *nonbuilding structure* such a standard may be used subject to the following limitations:
   a. The seismic ground acceleration and seismic coefficient shall be in conformance with the requirements of Sec. 4.1 and 4.2, respectively.
   b. The values for total lateral force and total *base* overturning moment used in design shall not be less than 80 percent of the *base shear* value and overturning moment, each adjusted for the effects of soil-*structure* interaction that would be obtained using the *Provisions*.
10. The *base shear* is permitted to be reduced in accordance with Sec. 5.5.7 to account for the effects of soil-*structure* interaction. In no case shall the reduced *base shear*, $\tilde{V}$, be less than $0.7V$.

14.5.1.1 Seismic Factors:

TABLE 14.5.1.1 Seismic Coefficients for Nonbuilding Structures

Nonbuilding Structure Type	*R*	Ω_0	C_d	Structural System and Height Limits (ft)[c]			
				Seismic Design Category			
				A & B	C	D	E & F
Nonbuilding frame systems:	See Table 5.2.2						
Concentric Braced Frames of Steel				NL	NL	NL	NL
Special Concentric Braced Frames of Steel				NL	NL	NL	NL
Moment Resisting Frame Systems:	See Table 5.2.2						
Special Moment Frames of Steel				NL	NL	NL	NL
Ordinary Moment Frames of Steel				NL	NL	50	50
Special Moment Frames of Concrete				NL	NL	NL	NL
Intermediate Moment Frames of Concrete				NL	NL	50	50
Ordinary Moment Frames of Concrete				NL	50	NP	NP
Steel *Storage Racks*	4	2	3-1/2	NL	NL	NL	NL
Elevated tanks, vessels, bins, or hoppers[a]:							
On braced legs	3	2	2-1/2	NL	NL	NL	NL
On unbraced legs	3	2	2-1/2	NL	NL	NL	NL
Irregular braced legs single pedestal or skirt supported	2	2	2	NL	NL	NL	NL
Welded steel	2	2	2	NL	NL	NL	NL
Concrete	2	2	2	NL	NL	NL	NL
Horizontal, saddle supported welded steel vessels	3	2	2-1/2	NL	NL	NL	NL
Tanks or vessels supported on structural towers similar to buildings	3	2	2	NL	NL	NL	NL
Flat bottom, ground supported tanks, or vessels:							
Anchored (welded or bolted steel)	3	2	2-1/2	NL	NL	NL	NL
Unanchored (welded or bolted steel)	2-1/2	2	2	NL	NL	NL	NL
Reinforced or prestressed concrete:							
Tanks with reinforced nonsliding *base*	2	2	2	NL	NL	NL	NL
Tanks with anchored flexible *base*	3	2	2	NL	NL	NL	NL
Tanks with unanchored and unconstrained:							
Flexible *base*	1-1/2	1-1/2	1-1/2	NL	NL	NL	NL
Other material	1 -/2	1-1/2	1-1/2	NL	NL	NL	NL
Cast-in-place concrete silos, stacks, and chimneys having *walls* continuous to the foundation	3	1-3/4	3	NL	NL	NL	NL

Nonbuilding Structure Type	*R*	Ω_0	C_d	Structural System and Height Limits (ft)[c]			
				Seismic Design Category			
				A & B	C	D	E & F
Reinforced masonry *structures*not similar to buildings	3	2	2-1/2	NL	NL	50	50
Nonreinforced masonry *structures* not similar to buildings	1-1/4	2	1-1/2	NL	50	50	50
Steel and reinforced concrete distributed mass cantilever *structures* not covered herein including stacks, chimneys, silos, and skirt-supported vertical vessels that are not similar to buildings	3	2	2-1/2	NL	NL	NL	NL
Trussed towers (freestanding or guyed), guyed stacks and chimneys	3	2	2-1/2	NL	NL	NL	NL
Cooling towers:							
Concrete or steel	3-1/2	1-3/4	3	NL	NL	NL	NL
Wood frame	3-1/2	3	3	NL	NL	50	50
Amusement *structures* and monuments	2	2	2	NL	NL	NL	NL
Inverted pendulum type *structures* (except elevated tanks, vessels, bins and hoppers)[b]	2	2	2	NL	NL	NL	NL
Signs and billboards	3-1/2	1-3/4	3	NL	NL	NL	NL
Self-supporting *structures*, tanks or vessels not covered above or by approved standards that are not similar to buildings	1-1/4	2	2-1/2	NL	50	50	50

[a] Support towers similar to building type *structures*, including those with irregularities (see Sec. 5.2.3 of the *Provisions* for definition of irregular *structures*) shall comply with the requirements of Sec. 5.2.6.

[b] Height shall be measured from the base.

NL = No limit.

14.5.1.2 Importance Factors and Seismic Use Group Classifications: The importance factor (I) and *seismic use group* for *nonbuilding structures* are based on the relative hazard of the contents, and the function. The value of I shall be the largest value determined by the approved standards, or the largest value as selected from Table 14.5.1.2 or as specified elsewhere in Chapter 14.

TABLE 14.5.1.2
Importance Factor (*I*) and Seismic Use Group Classification for Nonbuilding Structures

Importance Factor	I = 1.0	I = 1.25	I = 1.5
Seismic Use Group	**I**	**II**	**III**
Hazard	H - I	H - II	H - III
Function	F - I	F - II	F - III

H - I The nonbuilding structures that are not assigned to H-II or H-III.

H - II The nonbuilding structures that have a substantial public hazard due to contents or use as determined by the authority having jurisdiction.

H - III The nonbuilding structures containing sufficient quantities of toxic or explosive substance deemed to be hazardous to the public as determined by the authority having jurisdiction.

F - I *Nonbuilding structures* not classified as F - III.

F - II Not applicable for nonbuilding structures.

F - III The nonbuilding structures or designated ancillary nonbuilding structures that are required for post-earthquake recovery or as emergency back-up facilities for *Seismic Use Group* III *structures*.

14.5.2 Rigid Nonbuilding Structures: *Nonbuilding structures* that have a fundamental period, *T*, less than 0.06 sec, including their anchorages, shall be designed for the lateral force obtained from the following:

$$V = 0.30 S_{DS} W I \quad (14.2.2)$$

where:

V = the total design lateral seismic *base shear* force applied to a *nonbuilding structure*,

S_{DS} = the site design response acceleration as determined from Sec. 4.2.2,

W = *nonbuilding structure* operating weight.

I = the importance factor as determined from Table 14.2.1.2.

The force shall be distributed with height in accordance with Sec. 5.4.3.

14.5.3 Loads: The weight, *W*, for *nonbuilding structures* shall include all *dead loads* as defined for *structures* in Sec. 5.4.3. For purposes of calculating design *seismic forces* in *nonbuilding structures*, *W* also shall include all normal operating contents for items such as tanks, vessels, bins, and hoppers and the contents of piping. *W* shall include snow and ice loads when these loads constitute 25 percent or more of *W* or when required by the authority having jurisdiction based on local environmental characteristics.

14.5.4 Fundamental Period: The fundamental period of the nonbuilding *structure* shall be determined by methods as prescribed in Sec. 5.4.2 or by other rational methods.

14.5.5 Drift Limitations: The drift limitations of Sec. 5.2.8 need not apply to *nonbuilding structures* if a rational analysis indicates they can be exceeded without adversely effecting structural stability or attached or interconnected components and elements such as walkways and piping. *P-delta effects* shall be considered when critical to the function or stability of the *structure*.

14.5.6 Materials Requirements: The requirements regarding specific materials in Chapters 8, 9, 10, 11, and 12 shall be applicable unless specifically exempted in this chapter.

14.5.7 Deflection Limits and Structure Separation: Deflection limits and *structure* separation shall be determined in accordance with the *Provisions* unless specifically amended in this chapter.

14.5.8 Site-Specific Response Spectra: Where required by an approved standard or the authority having jurisdiction, specific types of nonbuilding structures shall be designed for site-specific criteria that accounts for local seismicity and geology, expected recurrence intervals and magnitudes of events from known seismic hazards as provided for in Sec. 4.1.3 of the *Provisions*. If a longer recurrence interval is defined in the approval standard for the nonbuilding structure such as LNG tanks, the recurrence interval required in the standard shall be used

14.6 NONBUILDING STRUCTURES SIMILAR TO BUILDINGS:

14.6.1 General: *Nonbuilding structures* that have structural systems that are designed and constructed in a manner similar to buildings and have a dynamic response similar to building s*tructures* shall be designed similar to building *structures* and in compliance with the *Provisions* with exceptions as contained in this section.

This general category of *nonbuilding structures* shall be designed in accordance with Sec. 14.5.

The lateral force design procedure for *nonbuilding structures* with structural systems similar to building *structures* (those with structural systems listed in Table 5.2.2) shall be selected in accordance with the force and detailing requirements of Sec. 5.2.1.

The combination of load effects, *E*, shall be determined in accordance with Sec. 5.2.7.

14.6.2 Pipe Racks:

14.6.2.1 Design Basis: Pipe racks supported at the base shall be designed to meet the force requirements of Sec. 5.4 or 5.5.

Displacements of the pipe rack and potential for interaction effects (pounding of the piping system) shall be considered using the amplified deflections obtained from the following formula:

$$\delta_x = \frac{C_d \delta_{xe}}{I} \qquad (14.6.2.1)$$

where:

C_d = the deflection amplification factor in Table 14.5.1.1,

δ_{xe} = the deflections determined using the prescribed seismic design forces of the *Provisions*, and

I = the importance factor determined from Table 14.5.1.2.

Exception: The importance factor, I, shall be determined from Table 14.5.1.2 for the calculation of δ_{xe}.

See Sec. 3.3.11 for the design of piping systems and their *attachments*. Friction resulting from *gravity loads* shall not be considered to provide resistance to *seismic forces*.

14.6.3 Steel Storage Racks: Steel storage racks supported at or below grade shall be designed in accordance with Sec. 14.6.3 and the following or, alternatively, with the method detailed in Section 2.7 of the RMI Specification provided that when determining the value of C_a in Sec. 2.7.3 of the RMI Specification, the value of C_s is taken as equal to $S_{DS}/2.5$, the value of C_v is taken as equal to S_{D1}, and the value of I_p shall not be taken as less than that required in Sec. 6.1.5 of the *Provisions*. In addition, the value of C_s in the RMI Specification shall not be less than $0.14S_{DS}$. For storage racks supported above grade, the value of C_s in the RMI Specification shall not be less than the value determined for F_p in accordance with Sec. 6.2 of the *Provisions* with R_p taken as equal to R and a_p taken as equal to 2.5.

14.6.3.1 General Requirements: Steel *storage racks* shall satisfy the force requirements of this section.

Exception: Steel *storage racks* supported at the *base* are permitted to be designed as *structures* with an R of 4 provided that the requirements of Chapter 2 are met. Higher values of R are permitted to be used when justified by test data approved in accordance with Sec. 1.2.6 or when the detailing requirements of Chapter 5 and 10 are met. The importance factor I shall be taken equal to the I_p values in accordance with Sec. 6.1.5

14.6.3.2 Operating Weight: Steel *storage racks* shall be designed for each of the following conditions of operating weight, W or W_p.

a. Weight of the rack plus every storage level loaded to 67 percent of its rated load capacity.

b. Weight of the rack plus the highest storage level only loaded to 100 percent of its rated load capacity.

The design shall consider the actual height of the center of mass of each storage load *component*.

14.6.3.3 Vertical Distribution of Seismic Forces: For all steel *storage racks*, the vertical distribution of *seismic forces* shall be as specified in Sec. 5.4.3 and in accordance with the following:

a. The *base shear*, V, of the typical *structure* shall be the *base shear* of the steel *storage rack* when loaded in accordance with Sec. 14.6.3.2.

b. The *base* of the *structure* shall be the floor supporting the steel *storage rack*. Each steel storage level of the rack shall be treated as a level of the *structure*, with heights h_i, and h_x measured from the *base* of the *structure*.

c. The factor *k* may be taken as 1.0.

d. The factor *I* shall be in accordance with Sec. 6.1.5.

14.6.3.4 Seismic Displacements: Steel *storage rack* installations shall accommodate the seismic *displacement* of the *storage racks* and their contents relative to all adjacent or attached *components* and elements. The assumed total relative *displacement* for *storage racks* shall be not less than 5 percent of the height above the base unless a smaller value is justified by test data or analysis approved in accordance with Sec. 1.5.

14.6.4 Electrical Power Generating Facilities:

14.6.4.1 General: Electrical power generating facilities are power plants that generate electricity by steam turbines, combustion turbines, diesel generators or similar turbo machinery.

14.6.4.2 Design Basis: Electrical power generating facilities shall be designed using the *Provisions* and the appropriate factors contained in Sec. 14.5.

14.6.5 Structural Towers for Tanks and Vessels:

14.6.5.1 General: Structural towers which support tanks and vessels shall be designed to meet the provisions of Sec 14.4. In addition, the following special considerations shall be included:

a. The distribution of the lateral *base shear* from the tank or vessel onto the supporting *structure* shall consider the relative stiffness of the tank and resisting structural elements.

b. The distribution of the vertical reactions from the tank or vessel onto the supporting *structure* shall consider the relative stiffness of the tank and resisting structural elements. When the tank or vessel is supported on grillage beams, the calculated vertical reaction due to weight and overturning shall be increased at least 20 percent to account for nonuniform support. The grillage beam and vessel attachment shall be designed for this increased design value.

c. Seismic *displacements* of the tank and vessel shall consider the *deformation* of the support *structure* when determining *P-delta effects* or evaluating required clearances to prevent pounding of the tank on the *structure*.

14.6.6 Piers and Wharves:

14.6.6.1 General: Piers and wharves are *structures* located in waterfront areas that project into a body of water or parallel the shore line.

14.6.6.2 Design Basis: Piers and wharves shall be designed to comply with the *Provisions* and approved standards. *Seismic forces* on elements below the water level shall include the inertial force of the mass of the displaced water. The additional seismic mass equal to the mass of the displaced water shall be included as a lumped mass on the submerged element, and shall be added to the calculated *seismic forces* of the pier or wharf *structure*. Seismic dynamic forces from the soil shall be determined by the registered design professional.

The design shall account for the effects of liquefaction on piers and wharfs as required.

14.7 NONBUILDING STRUCTURES NOT SIMILAR TO BUILDINGS:

14.7.1 General: *Nonbuilding structures* that have structural systems that are designed and constructed in a manner such that the dynamic response is not similar to buildings shall be designed in compliance with the *Provisions* with exceptions as contained in this section.

This general category of *nonbuilding structures* shall be designed in accordance with the *Provisions* and the specific applicable approved standards. Loads and load distributions shall not be less than those determined in the *Provisions*.

The combination of load effects, E, shall be determined in accordance with Sec. 5.2.6.2.

Exception: The redundancy/reliability factor, ρ, per Sec. 5.2.4 shall be taken as 1.

14.7.2 Earth Retaining Structures:

14.7.2.1 General: This section applies to all earth retaining *walls*. The applied *seismic forces* shall be determined in accordance with Sec. 7.5.1 with a geotechnical analysis prepared by a *registered design professional*.

14.7.3 Tanks and Vessels:

14.7.3.1 General: This section applies to all tanks, vessels, bins, and silos and similar containers storing liquids, gases, and granular solids supported at the base (hereafter referred to generically as tanks and vessels). Tanks and vessels covered herein include reinforced concrete, prestressed concrete, steel, and fiber-reinforced plastic materials.

14.7.3.2 Design Basis: Tanks and vessels storing liquids, gases, and granular solids shall be designed in accordance with the *Provisions* and shall be designed to meet the requirements of the applicable approved standards shown in Table 14.3 and Chapter 4 of the *Provisions* as defined in this section. Resistance to seismic forces shall be determined from a substantiated analysis based on the approved standards shown in Table 14.3.

h. Damping for the convective (sloshing) force component shall be taken as 0.5 percent

i. Impulsive and convective components may be combined by the direct sum or the square root of the sum of the square (SRSS) method when the modal periods are separated. If modal coupling may occur, the complete quadratic combination (CQC) method shall be used.

j. Vertical component of ground acceleration shall be considered in accordance with the appropriate national standard. If the approved national standard permits the user the option of including or excluding the vertical component of ground acceleration to comply with the *Provisions*, it shall be included. For tanks and vessels not covered by an approved national standard, the vertical seismic force shall be defined as 67 percent of the equivalent lateral force.

14.7.3.3 Strength and Ductility: Structural *components* and members that are part of the lateral support system shall be designed to provide the following:

a. Connections and *attachments* for anchorage and other lateral force resisting *components* shall be designed to develop the strength of the anchor (e.g., minimum published yield strength, F_y in direct tension, plastic bending moment) or Ω_o times the calculated element design load.

b. Penetrations, manholes, and openings in shell *components* shall be designed to maintain the strength and stability of the shell to carry tensile and compressive membrane shell forces.

c. Support towers for tanks and vessels with irregular bracing, unbraced panels, asymmetric bracing, or concentrated masses shall be designed using the provisions of Sec. 5.2.3 for irregular *structures*. Support towers using chevron or eccentric braced framing shall comply with the requirements of Sec. 5. Support towers using tension only bracing shall be designed such that the full cross section of the tension element can yield during overload conditions.

d. Compression struts that resist the reaction forces from tension braces shall be designed to resist the lesser of the yield strength of the brace ($A_g F_y$), or Ω_o times the calculated tension load in the brace.

e. The vessel stiffness relative to the support system (e.g., foundation, support tower, skirt) shall be considered in determining forces in the vessel, the resisting *components* and the connections.

f. For concrete liquid-containing *structures*, system ductility and energy dissipation under unfactored loads shall not be allowed to be achieved by inelastic deformations to such a degree as to jeopardize the serviceability of the *structure*. Stiffness degradation and energy dissipation shall be allowed to be obtained either through limited microcracking, or by means of lateral-force resistance mechanisms that dissipate energy without damaging the *structure*.

14.7.3.4 Flexibility of Piping Attachments: Piping systems connected to tanks and vessels shall consider the potential movement of the connection points during earthquakes and provide sufficient flexibility to avoid release of the product by failure of the piping system. The piping system and supports shall be designed so as to not impart significant mechanical loading on the attachment to the tank or vessel shell. Local loads at piping connections shall be considered in the design of the tank or vessel shell. Mechanical devices which add flexibility such as bellows, expansion joints, and other flexible apparatus may be used when they are designed for seismic loads and displacements.

Unless otherwise calculated, the minimum *displacements* in Table 14.7.3.4 shall be assumed. For attachment points located above the support or foundation elevation, the *displacements* in Table 14.7.3.4 shall be increased to account for drift of the tank or vessel.

TABLE 14.7.3.4 Minimum Displacements for Piping Attachments

Anchored Tanks or Vessels	**Displacements (inches)**
Vertical *displacement* relative to support or foundation	2
Horizontal (radial and tangential) relative to support or foundation	0.5
Unanchored Tanks or Vessels (at grade)	
Vertical *displacement* relative to support or foundation	
If designed to meet approved standard.	6
If designed for seismic loads per the provisions but not covered by an approved standard	12
For tanks and vessels with a diameter <40 ft, horizontal (radial and tangential) relative to support or foundation	8

When the elastic *deformations* are calculated, the minimum design *displacements* for piping *attachments* shall be the calculated *displacements* at the point of attachment increased by the amplification factor C_d.

The values given in Table 14.7.3.4 do not include the influence of relative movements of the foundation and piping anchorage points due to foundation movements (e.g., settlement, seismic *displacements*). The effects of the foundation movements shall be included in the piping system design including the determination of the mechanical loading on the tank or vessel, and the total displacement capacity of the mechanical devices intended to add flexibility.

14.7.3.5 Anchorage: Tanks and vessels at *grade* are permitted to be designed without anchorage when they meet the requirements for unanchored tanks in approved standards. Tanks and vessels supported above *grade* on structural towers or building *structures* shall be anchored to the supporting *structure*.

The following special detailing requirements shall apply to steel tank anchor bolts in seismic regions where $S_{DS} > 0.5$ or where the *structure* is classified as *Seismic Use Group* III.

a. Hooked anchor bolts (L or J shaped embedded bolts) or other anchorage systems based solely on bond or mechanical friction shall not be used when $S_{DS} \geq 0.33$. Post-installed anchors may be used provided that testing validates their ability to develop yield load in the anchor under cyclic loads in cracked concrete.

b. When anchorage is required, the anchor embedment into the foundation shall be designed to develop the minimum specified yield strength of the anchor.

14.7.3.6 Ground-Supported Storage Tanks for Liquids:

14.7.3.6.1 General: Ground-supported, flat bottom tanks storing liquids shall be designed to resist the seismic forces calculated using one of the following procedures:

a. The base shear and overturning moment calculated as if tank and the entire contents are a rigid mass system per Sec. 14.5.2 of the *Provisions* or

b. Tanks or vessels storing liquids in *Seismic Use Group* III or with a diameter greater than 20 ft shall be designed to consider the hydrodynamic pressures of the liquid in determining the equivalent lateral forces and lateral force distribution per the approved standards listed in Table 14.3 and Sec. 14.7.3 of the *Provisions*.

c. The force and *displacement* provisions of Sec. 14.5.4 of the *Provisions*.

The design of tanks storing liquids shall consider the impulsive and convective (sloshing) effects and consequences on the tank, foundation, and attached elements. The impulsive component corresponds to the high frequency amplified response to the lateral ground motion of the tank roof, shell and portion of the contents that moves in unison with the shell. The convective component corresponds to the low frequency amplified response of the contents in the fundamental sloshing mode. Damping for the convective component shall be 0.5 percent for the sloshing liquid unless otherwise defined by the approved national standard. The following definitions shall apply:

T_c = natural period of the first (convective) mode of sloshing,

T_i = fundamental period of the tank structure and impulsive component of the content,

T_v = natural period of vertical vibration of the liquid and tank structural system,

V_i = base shear due to impulsive component from weight of tank and contents,

V_c = base shear due to the convective component of the effective sloshing mass,

The seismic base shear is the combination of the impulsive and convective components:

$$V = V_i + V_c \tag{14.7.3.6.1}$$

where:

$$V_i = \frac{S_{ai} W_i}{R}$$

$$V_c = \frac{S_{ac} W_c}{R}$$

S_{ai} = the spectral acceleration as a multiplier of gravity including the site impulsive components at period T_i and 5 percent damping.

For $T_i < T_s$, $S_{ai} = S_{DS}$.

For $T_i > T_s$, $S_{ai} = \dfrac{S_{D1}}{T_i}$.

Note: When an approved national standard is used in which the spectral acceleration for the tank shell, and the impulsive component of the liquid is independent of T_i, then $S_{ai} = S_{DS}$ for all cases.

S_{ac} = the spectral acceleration of the sloshing liquid based on the sloshing period T_c and 0.5 percent damping.

For T_c < 4.0 sec, $S_{ac} = \dfrac{1.5 S_{D1}}{T_c}$

For T_c of 4.0 sec or greater, $S_{ac} = \dfrac{6 S_{D1}}{T_c^{\,2}}$

and $$T_c = 2\pi \sqrt{\frac{D}{3.68 g \tanh\left(\frac{3.68H}{D}\right)}}$$

where D = the tank diameter in feet, H = liquid height (feet or meters) and g = acceleration due to gravity in consistent units.

W_i = impulsive weight (impulsive component of liquid, roof and equipment, shell, bottom, and internal components,

W_c = the portion of the liquid weight sloshing.

The general design response spectra for ground-supported liquid storage tanks is shown in Figure 14.7.3.6-1.

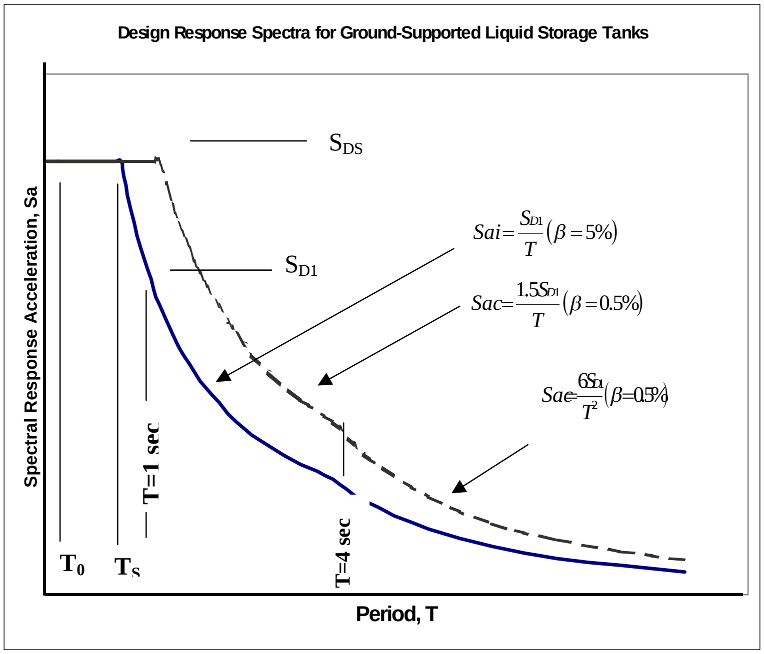

Figure 14.7.3.6-1

14.7.3.6.1.1 Distribution of Hydrodynamic and Inertia Forces: Unless otherwise required by the appropriate approved standard in Table 14.3, the method given in ACI 350.3 may be used to determine the vertical and horizontal distribution of the hydrodynamic and inertia forces on the walls of circular and rectangular tanks.

14.7.3.6.1.2 Freeboard: Sloshing of the liquid within the tank or vessel shall be considered in determining the freeboard required above the top capacity liquid level. A minimum freeboard shall be provided per Table 14.7.3.6.1.2. The height of the sloshing wave can be estimated by:

$$\delta_s = 0.5DIS_{ac} \qquad (14.7.3.6.1.2)$$

TABLE 14.7.3.6.1.2 Minimum Required Freeboard

Value of S_{DS}	**Seismic Use Group**		
	I	**II**	**III**
$S_{DS} < 0.167g$	*a*	*a*	$\delta_s^{\,c}$
$0.167g \le S_{DS} < 0.33g$	*a*	*a*	$\delta_s^{\,c}$
$0.33g \le S_{DS} < 0.50g$	*a*	$0.7\delta_s^{\,b}$	$\delta_s^{\,c}$
$0.50g \le S_{DS}$	*a*	$0.7\delta_s^{\,b}$	$\delta_s^{\,c}$

[a] No minimum freeboard is required.
[b] A freeboard equal to $0.7\delta_s$ is required unless one of the following alternatives is provided:
1. Secondary containment is provided to control the product spill.
2. The roof and supporting *structure* are designed to contain the sloshing liquid.

[c] Freeboard equal to the calculated wave height, δ_s, is required unless one of the following alternatives is provided:
1. Secondary containment is provided to control the product spill.
2. The roof and supporting *structure* are designed to contain the sloshing liquid.

14.7.3.6.1.3 Equipment and Attached Piping: Equipment, piping, and walkways or other appurtenances attached to the *structure* shall be designed to accommodate the *displacements* imposed by *seismic forces*. For piping *attachments,* see Sec. 14.7.3.4.

14.7.3.6.1.4 Internal Components: The *attachments* of internal equipment and accessories which are attached to the primary liquid or pressure retaining shell or bottom, or provide structural support for major *components* (e.g., a column supporting the roof rafters) shall be designed for the lateral loads due to the sloshing liquid in addition to the inertial forces. (See Wozniak and Mitchell, 1978).

14.7.3.6.1.5 Sliding Resistance: The transfer of the total lateral shear force between the tank or vessel and the subgrade shall be considered as follows:

a. For unanchored flat bottom steel tanks, the overall horizontal seismic shear force shall be resisted by friction, V_s, between the tank bottom and the foundation or subgrade. Unanchored storage tanks must be designed such that sliding will not occur when the tank is full of stored product. The maximum calculated seismic base shear, V_s, shall not exceed $W \tan 30^o$ ($V_s < W \tan 30^o$).

   V shall be determined using the effective weight of the tank, roof and contents after reduction for coincident vertical earthquake. Lower values of the friction factor should be used if the design of bottom to supporting foundation does not justify the friction value above (e.g., leak detection membrane beneath the bottom with a lower friction factor, smooth bottoms, etc).

b. No additional lateral anchorage is required for anchored steel tanks designed in accordance with approved standards.

c. The lateral shear transfer behavior for special tank configurations (e.g., shovel bottoms, highly crowned tank bottoms, tanks on grillage) can be unique and are beyond the scope of the provisions.

14.7.3.6.1.6 Local Shear Transfer: Local transfer of the shear from the *roof* to the *wall* and the *wall* of the tank into the *base* shall be considered. For cylindrical tanks and vessels, the peak local tangential shear per unit length shall be calculated by:

$$V_{\max} = \frac{2V}{\pi D} \qquad (14.7.3.6.1.6)$$

a. Tangential shear in flat bottom steel tanks shall be transferred through the welded connection to the steel bottom. This transfer mechanism is deemed acceptable for steel tanks designed in accordance with the approved standards and $S_{as} < 1.0$.

b. For concrete tanks with a sliding *base* where the lateral shear is resisted by friction between the tank *wall* and the *base*, the friction coefficient shall not exceed tan 30^{o}.

c. In fixed-*base* or hinged-*base* concrete tanks, the total horizontal seismic *base shear* is shared by membrane (tangential) shear and radial shear into the foundation. For anchored flexible-*base* concrete tanks, the majority of the *base shear* is resisted by membrane (tangential) shear through the anchoring system with only insignificant vertical bending in the *wall*. The connection between the *wall* and floor shall be designed to resist the maximum tangential shear.

14.7.3.6.1.7 Pressure Stability: For steel tanks, the internal pressure from the stored product stiffens thin cylindrical shell structural elements subjected to membrane compression forces. This stiffening effect may be considered in resisting seismically induced compressive forces if permitted by the approved standard or the building official having jurisdiction.

14.7.3.6.1.8 Shell Support: Steel tanks resting on concrete ring *walls* or slabs shall have a uniformly supported annulus under the shell. Uniform support shall be provided by one of the following methods:

a. Shimming and grouting the annulus,

b. Using fiberboard or other suitable padding

c. Using butt-welded bottom or annular plates resting directly on the foundation,

d. Using closely spaced shims (without structural grout) provided that the localized bearing loads are considered in the tank wall and foundation to prevent local crippling and spalling.

Anchored tanks shall be shimmed and grouted. Local buckling of the steel shell for the peak compressive force due to operating loads and seismic overturning shall be considered.

14.7.3.6.1.9 Repair, Alteration ,or Reconstruction: Repairs, modifications or reconstruction (i.e., cut down and re-erect) of a tank or vessel shall conform to industry standard practice and the *Provisions*. For welded steel tanks storing liquids, see API 653 and the approved national standard in Table 14.3. Tanks that are relocated shall be re-evaluated for the seismic loads for the new site and the requirements of new construction in accordance with the appropriate approved national standard and the *Provisions*.

14.7.3.7 Water and Water Treatment Tanks and Vessels:

14.7.3.7.1 Welded Steel: Welded steel water storage tanks and vessels shall be designed in accordance with the seismic requirements of AWWA D100 except that the design input forces shall be modified as follows:

The impulsive and convective components of the base shear are defined by the following equations for allowable stress design procedures:

$$V_i = \frac{S_{DS} I}{1.4R} W_i \qquad (14.7.3.7.1)$$

For $T_s < T_c < 4.0$ sec., $V_c = \frac{S_{DS} I}{1.4RT_c} W_c$.

For T_c of 4.0 sec or greater, $V_c = \frac{6S_{DS} I}{1.4R} \frac{T_s}{T_c^{\,2}} W_c$.

a. Substitute the above parameters into AWWA D100Eq. 13-4 and 13-8. Substitute the expression $\frac{S_{DS} I}{2.5(1.4R)} \ldots for \ldots \frac{ZI}{R_w}$ and substitute the term "*B*" for the term "*S*" in these equations in AWWA D100, where S_{DS} and T_S, are defined in Sec. 4.1.2.5, *R* is defined in Table 14.2.1.1, $B = 1.25T_s$ when T_c is in the range $T_s < T_c \leq 4.0$ sec, $B = 1.11T_S$ when T_c is > 4.0 sec.

Thus, AWWA D100 Eq. 13-4 for base shear at the bottom of the tank shell becomes:

$$V_{ACT} = \frac{18S_{DS} I}{2.5(1.4R)} \left[0.14\left(W_s + W_r + W_f + W_1\right) + BC_1 W_2\right]$$

Alternatively,

For *Ts* < *Tc* < 4.0 sec, $V_{ACT} = \frac{S_{DS} I}{1.4R} \left[\left(W_s + W_r + W_f + W_1\right) + 1.5 \frac{T_s}{T_c} W_2\right]$.

For *Tc* > 4.0 sec, $V_{ACT} = \frac{S_{DS} I}{1.4R} \left[\left(W_s + W_r + W_f + W_1\right) + 6 \frac{T_s}{T_c^{\,2}} W_2\right]$.

Similarly, AWWA D100 Eq. 13-8 for overturning moment applied to the bottom of the tank shell in AWWA D100 becomes:

$$M = \left[\frac{18S_{DS} I}{2.5(1.4R)}\right]\left[0.14\left(W_s X_s + W_r H_t + W_1 X_1\right) + BC_1 W_2 X_2\right]$$

b. The hydrodynamic seismic hoop tensile stress is defined in AWWA D100 Eq. 13-20 through 13-25. When using these equations, make the following substitution directly into the equations:

$$\frac{S_{DS}I}{2.5(1.4R)}.....for.....\left[\frac{ZI}{R_w}\right]$$

c. Sloshing height shall be calculated per Sec 14.7.3.7.1.2 instead of (Eq 13-26) of AWWA D100.

14.7.3.7.2 Bolted Steel: Bolted steel water storage *structures* shall be designed in accordance with the seismic requirements of AWWA D103 except that the design input forces shall be modified in the same manner shown in Sec 14.7.3.8.1 of the *Provisions*.

14.7.3.7.3 Reinforced and Prestressed Concrete: Reinforced and prestressed concrete tanks shall be designed in accordance with the seismic requirements of ACI 350.3 except that the design input forces shall be modified as follows:

a. For $T_I < T_o$, and $T_I > T_s$, substitute the term $\frac{S_a I}{1.4R}$ where S_a is defined in Sec. 4.1.2.6, Subsections 1, 2, or 3 or Eq. 4.1.2.6-3, for the terms in the appropriate equations as shown below:

For $\frac{ZIC_1}{R_1}$ shear and overturning moment equations of AWWA D110 and AWWA D115.

For $\frac{ZISC_1}{R_i}$ in the base shear and overturning moment equations of ACI 350.3.

b. For $T_o \le T_I \le T_s$, substitute the term $\frac{S_{DS} I}{1.4R}$ for terms $\frac{ZIC_i}{R_1}$ and $\frac{ZISC_i}{R_i}$.

c. For all values of T_c (or T_w), $\frac{ZIC_c}{R_c}$ and $\frac{ZISC_c}{R_c}$ are replaced by

$$\frac{6S_{D1} I}{T_c^{\,2}}..or..\left[\frac{6S_{DS} I}{T_c^{\,2}} T_S\right]$$

Thus, for $T_o \le T_I \le T_s$, AWWA D110 Eq. 4-1 becomes $V_I = \frac{S_{DS} I}{1.4R}(W_s + W_R + W_I)$ and Eq. 4-2 becomes $V_c = \frac{6 S_{DS} I}{1.4R}\left(\frac{T_s}{T_c^{\,2}}\right) W_C$ where S_a, S_{D1}, S_{DS}, T_0, and T_s are defined in Sec. 4.1.2.6 of the *Provisions*.

14.7.3.8 Petrochemical and Industrial Tanks and Vessels Storing Liquids:

14.7.3.8.1 Welded Steel: Welded steel petrochemical and industrial tanks and vessels storing liquids shall be designed in accordance with the seismic requirements of API 650 and API 620 except that the design input forces shall be modified as follows:

a. When using the equations in API 650 Sec. E.3, substitute the following into the equation for overturning moment M (where S_{DS} and T_s are defined in Sec. 4.1.2.5 of the *Provisions*). Thus,

   In the range $T_s < T_c \le 4.0$ sec, $C_2 = \frac{0.75S}{T_c} \ldots and \ldots S = 1.0$

$$M = S_{DS} I\left[0.24\left(W_s X_s + W_t H_t + W_1 X_1\right) + 0.80 C_2 T_2 W_2 X_2\right]$$

   In the range $T_w > 4.0$ sec,

$$M = S_{DS} I\left[0.24\left(W_s X_s + W_t H_t + W_1 X_1\right) + 0.71 C_2 T_s W_2 X_2\right] \quad \text{and}$$

$$C_2 = \frac{3.375S}{T_c^{\,2}} \ldots and \ldots S = 1.0$$

14.7.3.8.2 Bolted Steel: For bolted steel tanks used for storage of production liquids, API 12B covers the material, design, and erection requirements for vertical, cylindrical, and aboveground bolted tanks in nominal capacities of 100 to 10,000 barrels for production service. Unless required by the authority having jurisdiction, these temporary structures need not be designed for seismic loads. If design for seismic load is required, the loads may be adjusted for the temporary nature of the anticipated service life.

14.7.3.8.3 Reinforced and Prestressed Concrete: Reinforced concrete tanks for the storage of petrochemical and industrial liquids shall be designed in accordance with the force requirements of Sec. 14.7.3.8.3.

14.7.3.9 Ground-Supported Storage Tanks for Granular Materials

14.7.3.9.1 General: The intergranular behavior of the material shall be considered in determining effective mass and load paths, including the following behaviors:

a. Increased lateral pressure (and the resulting hoop stress) due to loss of the intergranular friction of the material during the seismic shaking.

b. Increased hoop stresses generated from temperature changes in the shell after the material has been compacted.

c. Intergranular friction which can transfer seismic shear directly to the foundation.

14.7.3.9.2 Lateral Force Determination: The lateral forces for tanks and vessels storing granular materials at grade shall be determined by the requirements and accelerations for short period structures (i.e., S_{as}).

14.7.3.9.3 Force Distribution to Shell and Foundation:

14.7.3.9.3.1 Increased Lateral Pressure: The increase in lateral pressure on the tank wall shall be added to the static design lateral pressure but shall not be used in the determination of pressure stability effects on the axial buckling strength of the tank shell.

14.7.3.9.3.2 Effective Mass: A portion of a stored granular mass will acts with the shell (the effective mass). The effective mass is related to the physical characteristics of the product, the height-to-diameter (*H/D*) ratio of the tank and the intensity of the seismic event. The effective mass shall be used to determine the shear and overturning loads resisted by the tank.

14.7.3.9.3.3 Effective Density: The effective density factor (that part of the total stored mass of product which is accelerated by the seismic event) shall be determined in accordance ACI 313.

14.7.3.9.3.4 Lateral Sliding: For granular storage tanks that have a steel bottom and are supported such that friction at the bottom to foundation interface can resist lateral shear loads, no additional anchorage to prevent sliding is required. For tanks without steel bottoms (i.e., the material rests directly on the foundation), shear anchorage shall be provided to prevent sliding.

14.7.3.9.3.5 Combined Anchorage Systems: If separate anchorage systems are used to prevent overturning and sliding, the relative stiffness of the systems shall be considered in determining the load distribution.

14.7.3.9.4 Welded Steel Structures: Welded steel granular storage *structures* shall be designed for Chapter 4 of the *Provisions*. Component allowable stresses and materials shall be per AWWA D100 except the allowable circumferential membrane stresses and material requirements in API 650 shall apply.

14.7.3.9.5 Bolted Steel Structures: Bolted steel granular storage *structures* shall be designed in compliance with Chapter 4 of the *Provisions*. Component allowable stresses and materials shall be per AWWA D103.

14.7.3.9.6 Reinforced Concrete Structures: Reinforced concrete *structures* for the storage of granular materials shall be designed in accordance with the force requirements of Chapter 4 of the *Provisions* and the requirements of ACI 313.

14.7.3.9.7 Prestressed Concrete Structures: Prestressed concrete *structures* for the storage of granular materials shall be designed in accordance with the force provisions of Chapter 4 of the *Provisions* and the requirements of ACI 313.

14.7.3.10 Elevated Tanks and Vessels for Liquids and Granular Materials:

14.7.3.10.1 General: This section applies to tanks, vessels, bins, and hoppers that are elevated above *grade* where the supporting tower is an integral part of the structure or where the primary function of the tower is to support the tank or vessel. Tanks and vessels that are supported within buildings, or are incidental to the primary function of the tower are considered mechanical equipment and shall be designed in accordance with Chapter 6 of the *Provisions*.

Elevated tanks shall be designed for the force and *displacement* requirements of the applicable approved standard, or Sec 14.5.

14.7.3.10.2 Effective mass: The design of the supporting tower or pedestal, anchorage, and foundation for seismic overturning shall assume the material stored is a rigid mass acting at the volumetric center of gravity. The effects of fluid-*structure* interaction may be considered in determining the forces, effective period, and mass centroids of the system if the following requirements are met:

a. The sloshing period, T_c is greater than $3T$ where T = natural period of the tank with confined liquid (rigid mass) and supporting *structure*.

b. The sloshing mechanism (i.e., the percentage of convective mass and centroid) is determined for the specific configuration of the container by detailed fluid structure interaction analysis or testing.

Soil-*structure* interaction may be included in determining T providing the provisions of Sec 2.5 are met.

14.7.3.10.3 *P*-Delta effects: The lateral drift of the elevated tank shall be considered as follows:

a. The design drift, the elastic lateral *displacement* of the stored mass center of gravity shall be increased by the factor C_d for evaluating the additional load in the support *structure*.

b. The *base* of the tank shall be assumed to be fixed rotationally and laterally

c. Deflections due to bending, axial tension or compression shall be considered. For pedestal tanks with a height to diameter ratio less than 5, shear *deformations* of the pedestal shall be considered.

d. The *dead load* effects of roof mounted equipment or platforms shall be included in the analysis.

e. If constructed within the plumbness tolerances specified by the approved standard, initial tilt need not be considered in the *P*-delta analysis.

14.7.3.10.4 Transfer of Lateral Forces into Support Tower: For post supported tanks and vessels that are cross braced:

a. The bracing shall be installed in such a manner as to provide uniform resistance to the lateral load (e.g., pretensioning or tuning to attain equal sag).

b. The additional load in the brace due to the eccentricity between the post to tank attachment and the line of action of the bracing shall be included.

c. Eccentricity of compression strut line of action (elements that resist the tensile pull from the bracing rods in the lateral force resisting systems) with their attachment points shall be considered.

d. The connection of the post or leg with the foundation shall be designed to resist both the vertical and lateral resultant from the yield load in the bracing assuming the direction of the lateral load is oriented to produce the maximum lateral shear at the post to foundation interface. Where multiple rods are connected to the same location, the anchorage shall be designed to resist the concurrent tensile loads in the braces.

14.7.3.10.5 Evaluation of Structures Sensitive to Buckling Failure: Shell structures that support substantial loads may exhibit a primary mode of failure from localized or general buckling of the support pedestal or skirt during seismic loads. Such structures may include single pedestal water towers, skirt supported process vessels, and similar single member towers. Where the structural assessment concludes that buckling of the support is the governing primary mode of failure, structures and components in *Seismic Use Group* III shall be designed to resist the seismic forces as follows:

a. The seismic response coefficient for this evaluation shall be per Sec 5.3.2.1 of the *Provisions* with *I/R* set equal to 1.0. Soil-structure and fluid-structure interaction may be utilized in determining the structural response. Vertical or orthogonal combinations need not be considered.

b. The resistance of the structure or component shall be defined as the critical buckling resistance of the element (i.e. a factor of safety set equal to 1.0).

c. The anchorage and foundation shall be designed to resist the load determined in item a. The foundation shall be proportioned to provide a stability ratio of 1.2 for the overturning moment. The maximum toe pressure under the foundation shall not exceed the ultimate bearing capacity or the lesser of 3 times the allowable bearing capacity. All structural components and elements of the foundation shall be designed to resist the combined loads with a load factor of 1.0 on all loads, including dead load, live load and earthquake load. Anchors shall be permitted to yield.

14.7.3.10.6 Welded Steel Water Storage Structures: Welded steel elevated water storage *structures* shall be designed and detailed in accordance with the seismic requirements of AWWA D100 and the *Provisions* except that the design input forces shall be modified by substituting the following terms for $\frac{ZIC}{R_w}$ in AWWA D100 Eq.13-1 and 13-3 of and set the value for S = 1.0.

For $T < Ts$, substitute the term $\frac{S_{DS} I}{1.4R}$.

For $Ts < T < 4.0$ sec, substitute the term $\frac{S_{D1} I}{T(1.4R)}$.

For T > 4.0 sec, substitute the term $\frac{S_{D1}I}{T^2(1.4R)}$.

14.7.3.10.6.1 Analysis Procedures: The equivalent lateral force procedure may be used. A more rigorous analysis shall be permitted. Analysis of single pedestal structures shall be based on a fixed-base, single-degree-of-freedom model. All mass, including the liquid, shall be considered rigid unless the sloshing mechanism (i.e., the percentage of convective mass and centroid) is determined for the specific configuration of the container by detailed fluid structure interaction analysis or testing. Soil-structure interaction may be included.

14.7.3.10.6.2 Structure Period: The fundamental period of vibration of the structure shall be established using the structural properties and deformational characteristics of the resisting elements in a substantiated analysis. The period used to calculate the seismic response coefficient shall not exceed 4.0 sec. See AWWA D100 for guidance on computing the fundamental period of cross braced structures.

14.7.3.10.7 Concrete Pedestal (Composite) Tanks: Concrete pedestal (composite) elevated water storage *structures* shall be designed in accordance with the requirements of ACI 371 except that the design input forces shall be modified as follows:

In ACI 371 Eq. 4-8a:

For $Ts < T < 4.0$ sec, substitute the term $\frac{S_{D1}I}{TR}$ for $\frac{1.2C_v}{RT^{2/3}}$

For T > 4.0 sec, substitute the term $\frac{4S_{D1}I}{T^2R}$ for $\frac{1.2C_v}{RT^{2/3}}$

In ACI 371 Eq. 4-8b, substitute the term $\frac{S_{DS}I}{R}$ for $\frac{2.5C_a}{R}$

In ACI 371 Eq. 4-9, substitute the term $0.2S_{DS}$ for $0.5C_a$.

14.7.3.10.7.1 Analysis Procedures: The equivalent lateral force procedure may be used for all structures and shall be based on a fixed-base, single-degree-of-freedom model. All mass, including the liquid, shall be considered rigid unless the sloshing mechanism (i.e., the percentage of convective mass and centroid) is determined for the specific configuration of the container by detailed fluid structure interaction analysis or testing. Soil-structure interaction may be included. A more rigorous analysis is permitted.

14.7.3.10.7.2 Structure Period: The fundamental period of vibration of the structure shall be established using the uncracked structural properties and deformational characteristics of the resisting elements in a properly substantiated analysis. The period used to calculate the seismic response coefficient shall not exceed 2.5 sec.

14.7.3.11 Boilers and Pressure Vessels:

14.7.3.11.1 General: *Attachments* to the pressure boundary, supports, and lateral force resisting anchorage systems for boilers and pressure vessels shall be designed to meet the force and *displacement* requirements of Sec 3.1.3 and 3.1.4 and the additional requirements of this section. Boilers and pressure vessels categorized as *Seismic Use Group* II or III shall be designed to meet the force and *displacement* requirements of Sec 3.1.3 and 3.1.4.

14.7.3.11.2 ASME Boilers and Pressure Vessels: Boilers or pressure vessels designed and constructed in accordance with ASME shall be deemed to meet the requirements of this section provided that the *displacement* requirements of Sec 3.1.3 and 3.1.4 are used with appropriate scaling of the force and *displacement* requirements to the working stress design basis.

14.7.3.11.3 Attachments of Internal Equipment and Refractory: *Attachments* to the pressure boundary for internal and external ancillary *components* (e.g., refractory, cyclones, trays) shall be designed to resist the *seismic forces* in the *Provisions* to safeguard against rupture of the pressure boundary. Alternatively, the element attached may be designed to fail prior to damaging the pressure boundary provided that the consequences of the failure does not place the pressure boundary in jeopardy. For boilers or vessels containing liquids, the effect of sloshing on the internal equipment shall be considered if the equipment can damage the integrity of the pressure boundary.

14.7.3.11.4 Coupling of Vessel and Support *Structure*: Where the mass of the operating vessel or vessels supported is greater than 25 percent of the total mass of the combined *structure*, the coupling of the masses shall be considered. Coupling with adjacent, connected *structures* such as multiple towers shall be considered if the *structures* are interconnected with elements that will transfer loads from one *structure* to the other.

14.7.3.11.5 Effective Mass: Fluid-*structure* interaction (sloshing) shall be considered in determining the effective mass of the stored material providing sufficient liquid surface exists for sloshing to occur and the T_c is greater than $3T$. Changes to or variations in material density with pressure and temperature shall be considered.

14.7.3.11.6 Other Boilers and Pressure Vessels: Boilers and pressure vessels that are designated *Seismic Use Group* III but are not designed and constructed in accordance with the requirements of ASME shall meet the following requirements:

The seismic loads in combination with other service loads and appropriate environmental effects shall not exceed the material strength shown in Table 14.7.3.11.6.

TABLE 14.7.3.11.6 Maximum Material Strength

Material	Minimum Ratio F_u/F_y	Max Material Strength Vessel Material	Max Material Strength Threaded Material[a]
Ductile (e.g., steel, aluminum, copper)	1.33 [b]	90%	70%
Semi-ductile	1.2 [c]	70%	50%
Nonductile (e.g., cast iron, ceramics, fiberglass)	NA	25%	20%

[a] Threaded connection to vessel or support system.
[b] Minimum 20% elongation per the ASTM material specification.

[c] Minimum 15% elongation per the ASTM material specification.

Consideration shall be made to mitigate seismic impact loads for boiler or vessel *components* constructed of nonductile materials or vessels operated in such a way that material ductility is reduced (e.g., low temperature applications).

14.7.3.11.7 Supports and Attachments for Boilers and Pressure Vessels: *Attachments* to the pressure boundary and support for boilers and pressure vessels shall meet the following requirements:

a. *Attachments* and supports transferring seismic loads shall be constructed of ductile materials suitable for the intended application and environmental conditions.

b. Seismic anchorages embedded in concrete shall be ductile and detailed for cyclic loads.

c. Seismic supports and *attachments* to *structures* shall be designed and constructed so that the support or attachment remains ductile throughout the range of reversing seismic lateral loads and *displacements*.

d. Vessel *attachments* shall consider the potential effect on the vessel and the support for uneven vertical reactions based on variations in relative stiffness of the support members, dissimilar details, non-uniform shimming or irregular supports. Uneven distribution of lateral forces shall consider the relative distribution of the resisting elements, the behavior of the connection details, and vessel shear distribution.

The requirements of Sec.14.5 and 14.7.3.10.5 shall also be applicable to this section.

14.7.3.12 Liquid and Gas Spheres:

14.7.3.12.1 General: *Attachments* to the pressure or liquid boundary, supports, and lateral force resisting anchorage systems for liquid and gas spheres shall be designed to meet the force and *displacement* requirements of Sec 3.1.3 and 3.1.4 and the additional requirements of this section. Spheres categorized as *Seismic Use Group* II or III shall themselves be designed to meet the force and *displacement* requirements of Sec 3.1.3 and 3.1.4.

14.7.3.12.2 ASME Spheres: Spheres designed and constructed in accordance with Division VIII of ASME shall be deemed to meet the requirements of this section providing the *displacement* requirements of Sec 3.1.3 and 3.1.4 are used with appropriate scaling of the force and *displacement* requirements to the working stress design basis.

14.7.3.12.3 Attachments of Internal Equipment and Refractory: *Attachments* to the pressure or liquid boundary for internal and external ancillary *components* (e.g., refractory, cyclones, trays) shall be designed to resist the *seismic forces* in the *Provisions* to safeguard against rupture of the pressure boundary. Alternatively, the element attached to the sphere could be designed to fail prior to damaging the pressure or liquid boundary providing the consequences of the failure do not place the pressure boundary in jeopardy. For spheres containing liquids, the effect of sloshing on the internal equipment shall be considered if the equipment can damage the pressure boundary.

14.7.3.12.4 Effective Mass: Fluid-*structure* interaction (sloshing) shall be considered in determining the effective mass of the stored material providing sufficient liquid surface exists for sloshing to occur and the T_c is greater than 3T. Changes to or variations in fluid density shall be considered.

14.7.3.12.5 Post- and Rod- Supported: For post-supported spheres that are cross braced:

a. The requirements of Sec. 14.7.3.10.4 shall also be applicable to this section.

b. The stiffening effect of (reduction in lateral drift) from pretensioning of the bracing shall be considered in determining the natural period.

c. The slenderness and local buckling of the posts shall be considered.

d. Local buckling of the sphere shell at the post attachment shall be considered.

e. For spheres storing liquids, bracing connections shall be designed and constructed to develop the minimum published yield strength of the brace. For spheres storing gas vapors only, bracing connection shall be designed for W_o times the maximum design load in the brace. Lateral bracing connections directly attached to the pressure or liquid boundary are prohibited.

14.7.3.12.6 Skirt Supported: For skirt-supported spheres, the following requirements shall apply:

a. The provisions of Sec. 14.7.3.10.5 also shall apply.

b. The local buckling of the skirt under compressive membrane forces due to axial load and bending moments shall be considered.

c. Penetration of the skirt support (e.g., manholes, piping) shall be designed and constructed to maintain the strength of the skirt without penetrations.

14.7.3.13 Refrigerated Gas Liquid Storage Tanks and Vessels:

14.7.3.13.1 General: The seismic design of the tanks and facilities for the storage of liquefied hydrocarbons and refrigerated liquids is beyond the scope of this section. The design of such tanks is addressed in part by various approved standards as listed in Table 14.3.

> **Exception:** Low pressure, welded steel storage tanks for liquefied hydrocarbon gas (e.g., LPG, butane) and refrigerated liquids (e.g., ammonia) could be designed in accordance with the requirements of Sec. 14.7.3.8 and API 620.

14.7.3.14 Horizontal, Saddle-Supported Vessels for Liquid or Vapor Storage:

14.7.3.14.1 General: Horizontal vessels supported on saddles (sometimes referred to as blimps) shall be designed to meet the force and *displacement* requirements of Sec 3.1.3 and 3.1.4.

14.7.3.14.2 Effective mass: Changes to or variations in material density shall be considered. The design of the supports, saddles, anchorage, and foundation for seismic overturning shall assume the material stored is a rigid mass acting at the volumetric center of gravity.

14.7.3.14.3 Vessel Design: Unless a more rigorous analysis is performed, vessels shall be designed as follows:

a. Horizontal vessels with a length to diameter ratio of 6 or more may be assumed to be a simply supported beam spanning between the saddles for determining the natural period of vibration and global bending moment.

b. Horizontal vessels with a length to diameter ratio of less than 6, the effects of “deep beam shear” shall be considered when determining the fundamental period and stress distribution.

c. Local bending and buckling of the vessel shell at the saddle supports due to seismic load shall be considered. The stabilizing effects of internal pressure shall not be considered to increase the buckling resistance of the vessel shell.

d. If the vessel is a combination of liquid and gas storage, the vessel and supports shall be designed both with and without gas pressure acting (assume piping has ruptured and pressure does not exist).

14.7.4 Stacks and Chimneys:

14.7.4.1 General: Stacks and chimneys are permitted to be either lined or unlined, and shall constructed from concrete, steel, or masonry.

14.7.4.2 Design Basis: Steel stacks, concrete stacks, steel chimneys, concrete chimneys, and liners shall be designed to resist seismic lateral forces determined from a substantiated analysis using approved standards. Interaction of the stack or chimney with the liners shall be considered. A minimum separation shall be provided between the liner and chimney equal to C_d times the calculated differential lateral drift.

14.7.5 Amusement Structures:

14.7.5.1 General: Amusement *structures* are permanently fixed *structures* constructed primarily for the conveyance and entertainment of people.

14.7.5.2 Design Basis: Amusement *structures* shall be designed to resist seismic lateral forces determined from a substantiated analysis using approved standards.

14.7.6 Special Hydraulic Structures:

14.7.6.1 General: Special hydraulic *structures* are *structures* that are contained inside liquid containing *structures*. These *structures* are exposed to liquids on both *wall* surfaces at the same head elevation under normal operating conditions. Special hydraulic *structures* are subjected to out of plane forces only during an earthquake when the *structure* is subjected to differential hydrodynamic fluid forces. Examples of special hydraulic *structures* include separation *walls*, baffle *walls*, weirs, and other similar *structures*.

14.7.6.2 Design Basis: Special hydraulic *structures* shall be designed for out-of-phase movement of the fluid. Unbalanced forces from the motion of the liquid must be applied simultaneously "in front of" and "behind" these elements.

Structures subject to hydrodynamic pressures induced by earthquakes shall be designed for rigid body and sloshing liquid forces and their own inertia force. The height of sloshing shall be determined and compared to the freeboard height of the *structure*.

Interior elements, such as baffles or roof supports, also shall be designed for the effects of unbalanced forces and sloshing.

14.7.7 Secondary Containment Systems:

14.7.7.1 General: Secondary containment systems such as impoundment dikes and walls shall meet the requirements of the applicable standards for tanks and vessels and the authority having jurisdiction.

Secondary containment systems shall be designed to withstand the effects of a *maximum considered earthquake* when empty and a *maximum considered earthquake* when full including all hydrodynamic forces.

14.7.7.2 Freeboard: Sloshing of the liquid within the secondary containment area shall be considered in determining the height of the impound. A minimum freeboard Sec 14.7.3.6.1.2, δ_s, shall be provided when:

$$\delta_s = 0.50 D S_{ac} \qquad (14.7.7.2)$$

where S_{ac} is determined per Sec. 14.7.3.6.1. For circular impoundment dikes, D shall be the diameter of the impoundment. For rectangular impoundment dikes, D shall be the longer longitudinal plan dimension.

Appendix to Chapter 14

ELECTRICAL TRANSMISSION, SUBSTATION, AND DISTRIBUTION STRUCTURES

PREFACE: This appendix is a resource document for future voluntary standards and model code development. The BSSC's Technical Subcommittee 13, Nonbuilding Structures has determined that this appendix material represents the current industry design practice for these types of *nonbuilding structures*.

These sections are included here so that the design community can gain familiarity with the concepts, update standards, and send comments on this appendix to the BSSC. It is hoped that the various consensus design standards will be updated to include the design and construction methodology presented in this appendix.

14A.1 REFERENCES:

IEEE 693 Institute of Electrical and Electronics Engineers (IEEE), *Recommended Practices for Seismic Design of Substations,* Power Engineering Society, Piscataway, New Jersey, 1997

14A.2 ELECTRICAL TRANSMISSION, SUBSTATION, AND DISTRIBUTION STRUCTURES:

14A.2.1 General: This section applies to electrical transmission, substation, and distribution *structures*.

Table 14A.2.1 Seismic Coefficients for Nonbuilding Structures

Nonbuilding Structure Type	R	Ω_0	C_d	Structural System and Height Limits (ft)[c]			
				Seismic Design Category			
				A & B	C	D	E & F
Electrical transmission towers, substation wire support *structures*, distribution *structures*							
Truss: Steel and aluminum	3	1-1/2	3	NL	NL	NL	NL

Nonbuilding Structure Type		***R***	***Ω_0***	***C_d***	**Structural System and Height Limits (ft)[c]**			
					Seismic Design Category			
					A & B	**C**	**D**	**E & F**
Pole:	Steel	1-1/2	1-1/2	1-1/2	NL	NL	NL	NL
	Wood	1-1/2	1-1/2	1-1/2	NL	NL	NL	NL
	Concrete	1-1/2	1-1/2	1-1/2	NL	NL	NL	NL
Frame:	Steel	3	1-1/2	1-1/2	NL	NL	NL	NL
	Wood	2-1/2	1-1/2	1-1/2	NL	NL	NL	NL
	Concrete	2	1-1/2	1-1/2	NL	NL	NL	NL
Telecommunication towers								
Truss:	Steel	3	1-1/2	3	NL	NL	NL	NL
Pole:	Steel	1-1/2	1-1/2	1-1/2	NL	NL	NL	NL
	Wood	1-1/2	1-1/2	1-1/2	NL	NL	NL	NL
	Concrete	1-1/2	1-1/2	1-1/2	NL	NL	NL	NL
Frame:	Steel	3	1-1/2	1-1/2	NL	NL	NL	NL
	Wood	2-1/2	1-1/2	1-1/2	NL	NL	NL	NL
	Concrete	2	1-1/2	1-1/2	NL	NL	NL	NL

14A.2.2 Design Basis: Electrical transmission, substation, wire support, and distribution *structures* shall be designed to resist a minimum seismic lateral load determined from the following formula:

$$V = \frac{C_s}{\left(\frac{R}{I}\right)} W$$

where:

V = seismic *base shear*;

I = importance factor, I = 1.0;

W = total *dead load* (does not include the supported wire or ice and snow loads applied to the tower);

R = response modification factor, Table 14A.2.1.1;

C_s = *seismic response coefficient* – S_{DS} but not greater then S_{D1}/T where S_{DS} and S_{D1} are as defined in Sec.1.4.2.2; and

T = The fundamental period of the tower.

A simplified static analysis and applying the seismic *base shear* (times a load factor of 1.0) at the center of mass of the *structure* can be used to determine if seismic load controls the design. The lateral force shall be evaluated in both the longitudinal and transverse directions to the support wire. When it is determined that seismic loads are significant (control the design of main load carrying members), a more detailed lateral force distribution shall be performed per Sec. 14.2.1 (with k = 1) of the *Provisions* and/or a modal analysis as specified by Sec. A.1.5 of IEEE 693.

Seismic lateral loads and design criteria for substation *equipment support structures* shall be in accordance with the requirements of IEEE 693. The design, manufacture, and inspection shall be in accordance with the quality control and quality assurance requirements of the industry design standards and recommended practices specified in Sec. 14.1.9.

14A.3 TELECOMMUNICATION TOWERS:

14A.3.1 General: This section applies to telecommunication towers.

14A.3.2 Design Basis: Self-supporting telecommunication towers shall be designed to resist a minimum seismic lateral force determined from the following formula:

$$V = \frac{C_s}{\left(\frac{R}{I}\right)} W \qquad (14A.5.2)$$

where:

V = seismic *base shear*;

I = importance factor, Table 14.2.1.2;

W = total *dead load* (including all *attachments*);

R = response modification factor, Table 14A.2.1.1; and

C_s = *seismic response coefficient* – S_{DS} but not greater then S_{D1}/T where S_{D1} and S_{DS}, are as defined in Sec. 4.2.2 and T is the fundamental period of the tower

A simplified static analysis applying the lateral load (times a load factor of 1.0) at the center of mass of the tower can be used to determine if seismic load controls the design of self-supporting towers. When it is determined that seismic loads are significant (control the design of main load carrying members), a more detailed lateral force distribution (with k = 1) and analysis shall be performed per Sec. 14.2.1 of the *Provisions*.

The lateral force applied to a telecommunication tower supported on a structure should account for the *base* motion input amplification as a result of the building earthquake response (see Sec. 14.1.2 of the *Provisions*). Guyed towers require a more detailed computer analysis including nonlinear analysis and guy-tower interaction effects. An industry accepted modal analysis procedure should be used for guyed towers.

The design, manufacture, and inspection shall be in accordance with the quality control and quality assurance requirements of the industry design standards and recommended practices specified in Sec. 14.1.9.

14A.4 BURIED STRUCTURES:

14A.4.1 General: Buried *structures* are subgrade *structures* such as tanks, tunnels, and pipes. Buried *structures* that are designated as *Seismic Use Group* II or III or are of such a size or length to warrant special seismic design as determined by the registered design professional shall be identified in the geotechnical report.

14A.4.2 Design Basis: Buried *structures* shall be designed to resist minimum seismic lateral forces determined from a substantiated analysis using approved procedures. Flexible couplings shall be provided for buried *structures* requiring special seismic considerations where changes in the support system, configuration, or soil condition occur.

14A.5 PERFORMANCE CRITERIA FOR TANKS AND VESSELS: Tanks and vessels shall be designed to meet the following minimum post-earthquake performance criteria. These criteria depend on the Seismic Use Group (category) classification and content-related hazards of the tanks and vessels being considered:

TABLE 14A.5 Performance Criteria for Tanks and Vessels

Performance Category[a]	Minimum Post-Earthquake Performance
I[b]	The structure shall be permitted to fail provided the resulting spill does not pose a threat to the public or to adjoining Category I, II or III structures.
II	The structure shall be permitted to sustain localized damage, including minor leaks, provided (a) such damage remains localized and does not propagate; and (b) the resulting leakage does not pose a threat to the public or to adjoining Category I, II or III structures.
III	The structure shall be permitted to sustain minor damage, and its operational systems or components (valves and controls) shall be permitted to become inoperative, provided that (a) the structure retains its ability to contain 100% of its contents; and (b) the structure's minor damage, and the failure of its operational systems or components, are not accompanied by, or lead to, leakage.
IV	The structure shall be permitted to sustain minor damage provided that (a) it shall retain its ability to contain 100% of its contents without leakage; and (b) its operational systems or components shall remain fully operational.

[a] Performance Categories I, II, and III correspond to the Seismic Use Groups defined in Sec. 1.3 and tabulated in Tables 14.2.1.2 and 14.7.3.7.1.2.

[b] For tanks and vessels in Performance Category IV, an Importance Factor I = 1.0 shall be used.