Changes to the Nonbuilding Structures Provisions in ASCE 7-10

J. G. (Greg) Soules, P.E., S.E., F. ASCE
ASCE 7 Seismic Subcommittee
Chair, Nonbuilding Structures Task Committee

ASCE | KNOWLEDGE & LEARNING

Changes to the Nonbuilding Structures Provisions in ASCE 7-10

- Concrete Stacks and Chimneys
- Modifications to the Seismic Requirements of ACI 350.3
- Sloshing Wave Height in Tanks
- Anchorage Requirements for Nonbuilding Structures
- Steel Storage Rack Requirements

Changes to the Nonbuilding Structures Provisions in ASCE 7-10

- Piers and Wharves Clarification
- Skirt Supported Vessel Clarification
  - R-Value
  - Critical Buckling Check
- Adoption of New API 620 Appendix L
- Refrigerated Gas Liquid Storage Tank Clarification
- Masonry Structures Clarification

Significant Changes to Chapter 15

Concrete Stacks and Chimneys

- Concrete chimneys have low ductility.
- Their seismic behavior is especially critical in the opening regions due to inherent reduction in strength and loss of confinement for vertical reinforcement in the jamb regions around the openings.
- A spectacular earthquake-induced chimney failure occurred in Izmit, Turkey in 1999 and has been attributed to strength and detailing problems.

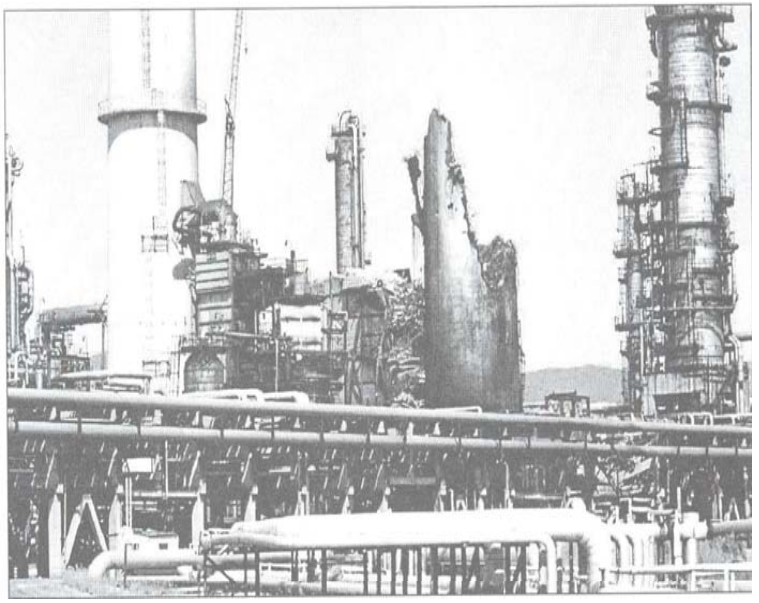


Photo from TCLEE Monograph 17

Concrete Stacks and Chimneys

- The new requirements adopted by ASCE 7 for the 2010 edition accomplishes four objectives:
  1. It modifies Section 15.6.2 by providing language to permit the use of ACI 307 for design under certain conditions which will make the resulting design consistent with ASCE 7.
  2. It separates out stacks and chimneys designed to the requirements of ACI 307 and the detailing requirements of Section 15.6.2 and provides values of R, Ω_0 and C_d. The R and Ω_0 values of 2.0 and 1.5 are based on the recommendations of the ACI 307 committee. The C_d value is set equal to the R value.

Concrete Stacks and Chimneys

- The new requirements adopted by ASCE 7 for the 2010 edition accomplishes four objectives:
  3. It adds stacks and chimneys designed to ACI 307 to the EXCEPTION list that are permitted to use the lower nonbuilding structure minimum base shear values.
  4. Finally it provides specific opening detailing requirements as shown on the next slide.

Concrete Stacks and Chimneys

- For concrete chimneys and stacks assigned to SDC D, E, and F, splices for vertical rebar must be staggered such that no more than 50% of the bars are spliced at any section and alternate lap splices are staggered by the development length.
- Where the loss of cross-sectional area is greater than 10%, cross-sections in the regions of breachings/openings must be designed and detailed for vertical force, shear force, and bending moment demands along the vertical direction, determined for the affected cross-section using an overstrength factor of 1.5.
- The region where the overstrength factor applies must extend above and below the opening(s) by a distance equal to half of the width of the largest opening in the affected region.

Concrete Stacks and Chimneys

- The jamb regions around each opening must be detailed using the column tie requirements in Section 7.10.5 of ACI 318. Such detailing must extend for a jamb width of a minimum of two times the wall thickness and for a height of the opening height plus twice the wall thickness above and below the opening, but no less than the development length of the longitudinal bars.
- The percentage of longitudinal reinforcement in jamb regions must meet the requirements of Section 10.9 of ACI 318 for compression members.

Modifications to the Seismic Requirements of ACI 350.3

- ACI 350.3-06, *Seismic Design of Liquid-Containing Concrete Structures and Commentary,* does not agree with the seismic provisions of ASCE 7.
- As a result, several modifications to ACI 350.3-06 were added to ASCE 7 Section 15.7.7.3

Modifications to the Seismic Requirements of ACI 350.3

- The importance factor, I_e, must be determined according to Section 15.4.1.1, the response modification coefficient, R, must be taken from Table 15.4-2.
- The importance factor and response modification factor for a structure are to be specified by ASCE 7 and not the reference document.
- It is not uncommon for a reference document to repeat the importance factor and response modification factor from ASCE 7.
- The descriptions used to determine the applicable values of the importance factor and response modification factor found in ACI 350.3-06 do not exactly match those used in ASCE 7.

Modifications to the Seismic Requirements of ACI 350.3

Table 4.1.1(a)—Importance factor *I*

	Tank use	Factor *I*
III	Tanks containing hazardous materials*	1.5
II	Tanks that are intended to remain usable for emergency purposes after an earthquake, or tanks that are part of lifeline systems	1.25
I	Tanks not listed in Categories II or III	1.0

*In some cases, for tanks containing hazardous materials, engineering judgment may require a factor $I > 1.5$.

Use or Occupancy of Buildings and Structures	Risk Category	I_E
Buildings and other structures that represent a low risk to human life in the event of failure.	I	1.0
All buildings and other structures except those listed in Risk Categories I, III, and IV	II	1.0
Buildings and other structures, the failure of which could pose a substantial risk to human life. Buildings and other structures, not included in Occupancy Category IV, with potential to cause a substantial economic impact and/or mass disruption of day-to-day civilian life in the event of failure Buildings and other structures not included in Risk Category IV (including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, hazardous waste, or explosives) containing toxic or explosive substances where the quantity of the material exceeds a threshold quantity established by the authority having jurisdiction and is sufficient to pose a threat to the public if released.	III	1.25
Buildings and other structures designated as essential facilities. Buildings and other structures, the failure of which could pose a substantial hazard to the community. Buildings and other structures (including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, or hazardous waste) containing sufficient quantities of highly toxic substances where the quantity exceeds a threshold quantity established by the authority having jurisdiction to be dangerous to the public if released and is sufficient to pose a threat to the public if released. a Buildings and other structures required to maintain the functionality of other Category IV structures.	IV	1.5

Modifications to the Seismic Requirements of ACI 350.3

Table 4.1.1(b)—Response modification factor *R*

Type of structure	R_i		R_c
	On or above grade	Buried*	
Anchored, flexible-base tanks	3.25†	3.25†	1.0
Fixed or hinged-base tanks	2.0	3.0	1.0
Unanchored, contained, or uncontained tanks‡	1.5	2.0	1.0
Pedestal-mounted tanks	2.0	—	1.0

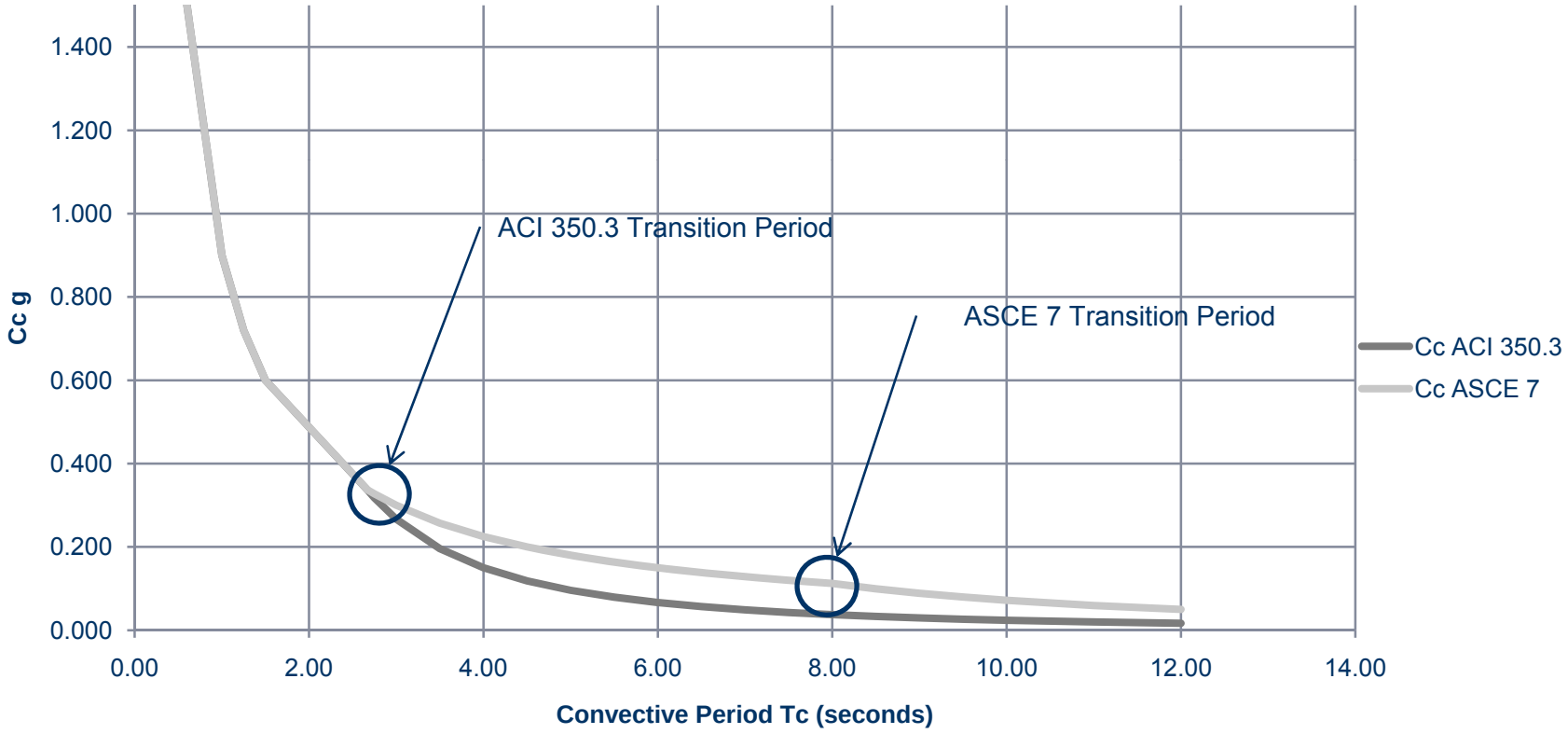
*Buried tank is defined as a tank whose maximum water surface at rest is at or below ground level. For partially buried tanks, the R_i value may be linearly interpolated between that shown for tanks on grade and for buried tanks.
†R_i = 3.25 is the maximum R_i value permitted to be used for any liquid-containing concrete structure.
‡Unanchored, uncontained tanks shall not be built in locations where $S_{DS} \geq 0.75$.

Nonbuilding Structure Type	Detailing Requirements[c]	R
Flat-bottom ground-supported tanks:	15.7	
Steel or fiber-reinforced plastic:		
Mechanically anchored		3
Self-anchored		2.5
Reinforced or prestressed concrete:		
reinforced nonsliding base		2
anchored flexible base		3.25
unanchored and unconstrained flexible base		1.5
All other		1.5

Modifications to the Seismic Requirements of ACI 350.3

- The ground motions for determining the convective (sloshing) seismic forces specified in ACI 350.3-06 are not the same and are actually lower than those specified by ASCE 7.
- S_{ac} must be substituted for C_c in ACI 350.3 Section 9.4.2 using Equations 15.7-10 for $T_c \leq T_L$ and 15.7-11.for $T_c > T_L$ from Section 15.7.6.1.
- Just as with the importance factor and response modification factor discussed previously, ground motions are to be specified by ASCE 7 and not the reference document.

Modifications to the Seismic Requirements of ACI 350.3



Modifications to the Seismic Requirements of ACI 350.3

- The previous slide is based on the following ground motions:
  - S_S = 1.5, S_1 = 0.6
  - Site Class D
  - Risk Category II (I_E = 1.0)
  - T_L = 8 seconds

Modifications to the Seismic Requirements of ACI 350.3

- Comments on ACI 350.3 Differences
  - Convective forces determined using ACI 350.3 can be on the order of 1/3 of those calculated using ASCE 7.
  - Smaller Convective R-value (1.0 vs. 1.5) in ACI 350.3 some what compensates for the under estimation of convective forces.
  - ACI 350.3 essentially redefines the long-period transition period, T_L, as $1.6/T_S$ where T_S is equal to S_{D1}/S_{DS}.
  - This alternate transition period allows large diameter tanks to have significantly lower convective forces and lower seismic freeboard than permitted by ASCE 7.

Modifications to the Seismic Requirements of ACI 350.3

- The vertical ground motions specified in ACI 350.3-06 and defined by C_t are not the same as those specified by ASCE 7.
- The value of C_t from ACI 350.3 Section 9.4.3 must be determined using the procedures of Section 15.7.2(c). The values of I, R_i, and b as defined in ACI 350.3 shall be taken as 1.0 in the determination of vertical seismic effects.

Sloshing Wave Height in Tanks

- The long-period transition period, T_L, has a significant effect on the magnitude of the sloshing wave height in liquid storage tanks.
- Prior to the 2005 Edition of ASCE 7, the value of T_L was assumed to be 4 seconds.
- With the release of ASCE 7-05, T_L became a variable that ranged from 4 seconds to 16 seconds.

Sloshing Wave Height in Tanks

- The freeboard requirements significantly increased the cost of large diameter liquid storage tanks.
- Actual site specific studies carried out since the introduction of the T_L maps of ASCE 7-05 indicate that the mapped values of T_L are extremely conservative.
- Because a revision of the T_L maps was not possible in this revision cycle, ASCE 7 has been revised to allow the use of site specific values that are less than the mapped values with a floor of 4 seconds or one-half the mapped value of T_L.

Sloshing Wave Height in Tanks

- Also, the 80 percent limit on S_a required by Sections 21.3 and 21.4 does not apply to the determination of site-specific values of the convective acceleration, S_{ac}.

Product Loss Due to No Freeboard

Sloshing Wave Height in Tanks

- Another source of excessive seismic freeboard in liquid storage tanks is ASCE 7-05 Equation 15.7-13, $\delta_s = 0.5 D_i I S_{ac}$.
- Prior to the introduction of this equation, the actual theoretical value of the sloshing wave, $\delta_s = 0.42 D_i I S_{ac}$ was typically used.
- The introduction of Equation 15.7-13 introduced substantial additional height requirements on large diameter liquid storage tanks located in high seismic regions.

Sloshing Wave Height in Tanks

- The use maximum direction ground motions eliminates the need for rounding the equation up to 0.5.
- This rounding decision increased freeboard by 19%.
- ASCE 7-10 will revert back to the theoretical value.

Anchorage Requirements for Nonbuilding Structures

- Many nonbuilding structures rely on the ductile behavior of anchor bolts to justify the R value assigned to the structure.
- Anchor bolts used for tanks and vessels must stretch under seismic loads to provide the required ductility.

Stretched Bolt on Stack
February 27, 2010 Chile Earthquake

Anchorage Requirements for Nonbuilding Structures

- The addition of Section 15.4.9 provides a consistent treatment of anchorage on nonbuilding structures.
  - Anchors in concrete used for nonbuilding structure anchorage must be designed in accordance with Appendix D of ACI 318.
  - Anchors in masonry used for nonbuilding structure anchorage must be designed in accordance with ACI 530. Anchors must be designed to be governed by the tensile or shear strength of a ductile steel element.
  - Post-installed anchors in concrete or masonry must be pre-qualified for seismic applications.

Anchorage Requirements for Nonbuilding Structures

- Changes to 15.7.3 are intended to ensure that anchor attachments are designed such that the anchor will yield (stretch) before the anchor attachment to the structure fails.
- It also clarifies that the anchor rod embedment requirements are to be based on the requirements of 15.7.5 and not 15.7.3(a). This again is to ensure that the anchor yields before the anchor attachment fails.

Anchorage Requirements for Nonbuilding Structures

- The revised requirements of Section 15.7.3 can be summarized as follows:
  - Connections, excluding anchors (bolts or rods) embedded in concrete, must be designed to develop Ω_0 times the calculated connection design force.
  - For anchors embedded in concrete, the design of the anchor embedment must meet the requirements of 15.7.5. Additionally, the connection of the anchor to the tank or vessel must be designed to develop the lesser of the strength of the anchor in tension as determined by the reference document or Ω_0 times the calculated anchor design force.

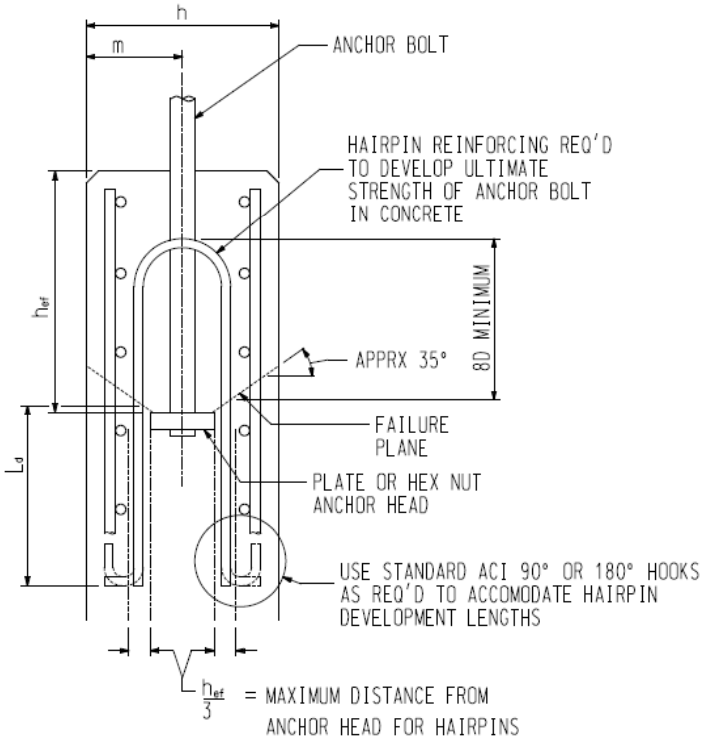
Anchorage Requirements for Nonbuilding Structures

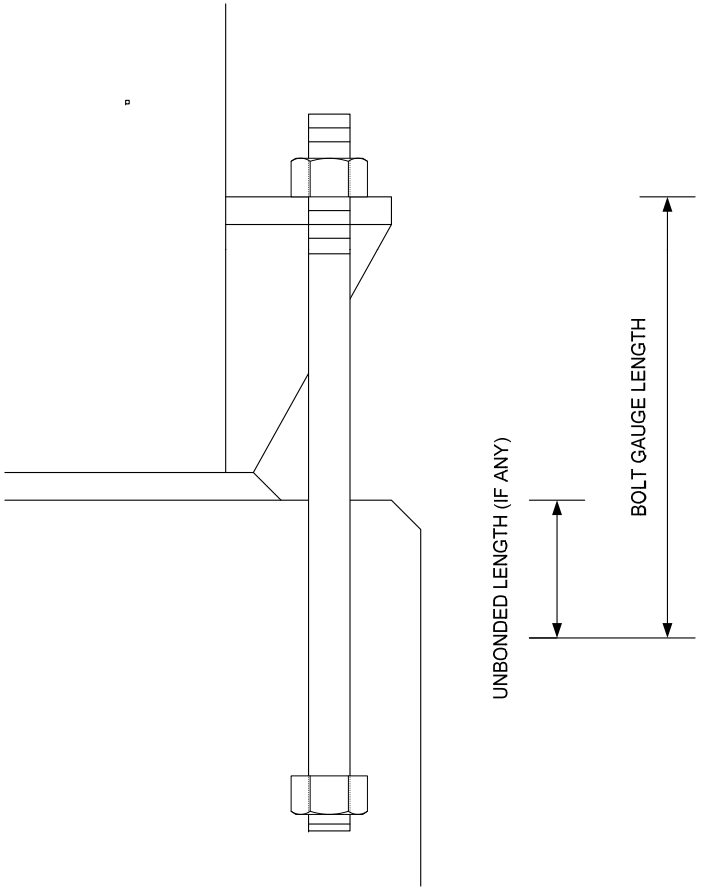
- The changes to 15.7.5 are to update the requirements for anchor bolts and anchor bolt embedment design to meet ACI 318 Appendix D.
- The revised requirements of Section 15.7.5 can be summarized as follows:
  - Anchorage must be in accordance with Section 15.4.9, whereby the anchor embedment into the concrete must be designed to develop the steel strength of the anchor in tension. The steel strength of the anchor in tension must be determined in accordance with ACI 318 Appendix D Equation D-3. The anchor must have a minimum gauge length of eight diameters.

Anchorage Requirements for Nonbuilding Structures

- The revised requirements of Section 15.7.5 can be summarized as follows:
  - Post-installed anchors are permitted to be used in accordance with Section 15.4.9.3 provided the anchor embedment into the concrete is designed to develop the steel strength of the anchor in tension.
  - The load combinations with overstrength of Section 12.4.3 are not to be used to size the anchor bolts for tanks, horizontal and vertical vessels.
  - These requirements only apply to structures located in SDC C, D, E, and F.

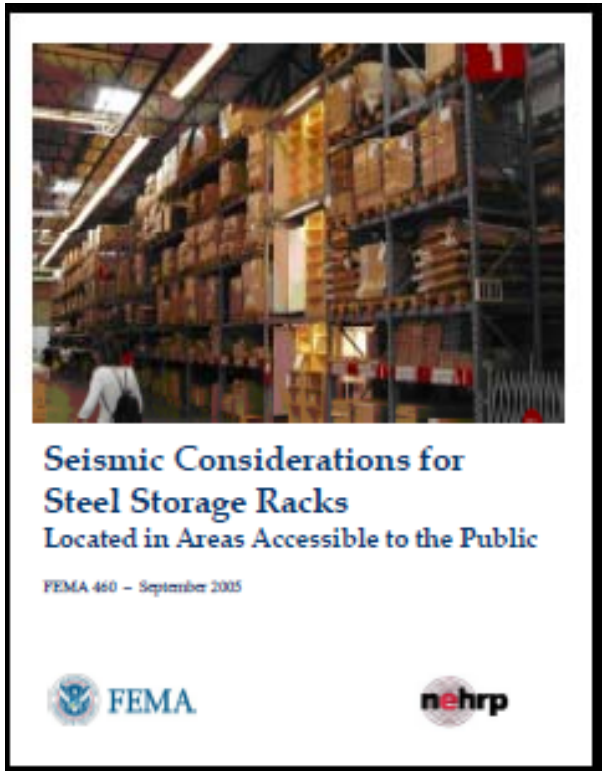
Anchorage Requirements for Nonbuilding Structures





Steel Storage Rack Requirements

- ANSI MH 16.1-2008, *Specification for the Design, Testing, and Utilization of Industrial Steel Storage Racks*, is designed to be a stand-alone standard to be adopted by reference.
- Working with FEMA/BSSC TS-8 and ASCE 7, and the Task Group on FEMA/BSSC 460(2005), seismic provisions have been developed and stated to be self-sufficient, incorporating the results of the work of those efforts.



Steel Storage Rack Requirements

- Unfortunately, there is still one area in ANSI MH 16.1-2008 where the requirements are lacking.
- The anchorage provisions of MH 16.1-2008 are not in conformance with ASCE 7.

Steel Storage Rack Requirements

- The additional anchorage requirements of Sections 15.5.3.2 and 15.5.3.3 can be summarized as follows:
  - Design forces that include seismic loads for anchorage of steel storage racks to concrete must be determined using load combinations with overstrength provided in Section 12.4.3.2 ASCE 7. The overstrength factor shall be taken as 2.0.
  - Anchorage of steel storage racks to concrete must be in accordance with the requirements of Section 15.4.9 of ASCE 7.

Steel Storage Rack Requirements

- The additional anchorage requirements of Sections 15.5.3.2 and 15.5.3.3 can be summarized as follows:
  - Shims that are a total thickness of less than or equal to six times the anchor bolt diameter under bases with less than two anchor bolts must be interlocked or welded together in a fashion that is capable of transferring all the shear forces at the base.
  - Bending in the anchor associated with shims or grout under the base plate must be taken into account in the design of the anchor bolts.

Clarifications to Chapter 15

Piers and Wharves Clarification

- Piers and Wharves are addressed in Section 15.5.6 of ASCE 7-05.
- **ONLY** piers and wharves that are accessible to the general public are within the scope of ASCE 7-05.
- During the public ballot phase for ASCE 7-10, the ASCE 7 committee found out that building officials on the West Coast were misinterpreting the wording of Section 15.5.6 and applying the requirements of ASCE 7-05 to **ALL** piers and wharves.

Piers and Wharves Clarification

- The ASCE 7 committee decided to add two editorial clarifying statements.
- In Chapter 11, revise 11.1.2 to add the following to the list of exempt structures:
  - 5. Piers and wharves that are not accessible to the general public.
- In Chapter 15, Revise 15.5.6.2 to add the following sentence to the end of the first paragraph:
  - Piers and wharves that are not accessible to the general public are beyond the scope of this section.

Skirt Supported Vessel Clarifications

- Skirt supported vessels fail in buckling, which is not a ductile failure mode. Therefore, a more conservative design approach is required.
- To prevent collapse, ASCE 7 Sect. 15.7.10 and *T*able 15.4-2 require skirt supported vessels to be checked for seismic loads based on R/I = 1.0 if the structure falls in Risk Category IV or if an R-value of 3.0 is used in the design of the vessel.

Skirt Supported Vessel Clarifications

- It became clear to the ASCE 7 Seismic Subcommittee that users were not applying the provisions for skirt supported vertical vessels as intended.
- It was also learned that major software packages used in the design of skirt supported vessels failed to incorporate these requirements.
- Therefore, Section 15.7.10.5 and Table 15.4-2 were revised to make the committee's intent clear.

Skirt Supported Vessel Clarifications

- To make it clear that special detailing requirements were required to use R=3, Table 15.4-2 was revised to consolidate requirements.
- Previously, two separate entries existed in Table 15.4-2 that could be used for choosing the R-value and detailing requirements for skirt supported vessels.

Skirt Supported Vessel Clarifications

- The revised entry in Table 15.4-2 shown below should end the confusion experienced by users.

Nonbuilding Structure Type	Detailing Requirements[c]	*R*
All steel and reinforced concrete distributed mass cantilever structures not otherwise covered herein including stacks, chimneys, silos, skirt-supported vertical vessels and single pedestal or skirt supported	15.6.2	
Welded steel	15.7.10	2
Welded steel with special detailing[e]	15.7.10 & 15.7.10.5 a and b	3
Prestressed or reinforced concrete	15.7.10	2
Prestressed or reinforced concrete with special detailing	15.7.10 and ACI 318 Chapter 21, Sections 21.2 and 21.7	3

Skirt Supported Vessel Clarifications

- In addition to the changes made to Table 15.4-2, Section 15.7.10.5 was revised as shown to the right.

15.7.10.5 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 due to 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 specified in this standard to be designed to subsections a and b below and those that are assigned as Risk Category IV shall be designed to resist the seismic forces as follows:

a. The seismic response coefficient for this evaluation shall be in accordance with Section 12.8.1.1 of this standard with I_e/R set equal to 1.0. Soil–structure and fluid–structure interaction is permitted to be utilized in determining the structural response. Vertical or orthogonal combinations need not be considered.
b. The resistance of the structure shall be defined as the critical buckling resistance of the element, that is, a factor of safety set equal to 1.0.

Skirt Supported Vessel Clarifications

- The R/I = 1.0 check will typically govern the design of the skirt over using loads determined with an R-factor of 3 in a moderate to high area of seismic activity.
- The only benefit of using an R-factor of 3 in this case is in the design of the foundation.
- The foundation is not required to be designed for the R/I = 1.0 load.

Skirt Supported Vessel Clarifications

- For the R/I = 1.0 load, the skirt can be designed based on critical buckling (factor of safety of 1.0).
- The critical buckling strength of a skirt can be determined using a number of published sources.
- The two most common methods for determining the critical buckling strength of a skirt are *ASME BPVC* Section VIII, Division 2 Paragraph 4.4 using a factor of safety of 1.0 and *AWWA D-100* Section 13.4.3.4.

Adoption of New API 620 Appendix L

- API 620 is a reference document that applies to ground supported storage tanks storing liquids under pressure up to 15 psig.
- In ASCE 7-05, API 620 tanks were required to be designed for seismic forces using the rules of API 650 Appendix E.
- The latest edition of API 620 now conforms to the requirements of ASCE 7.

Adoption of New API 620 Appendix L

- It should be noted that API 620 Appendix L requires a higher seismic performance level for refrigerated and cryogenic storage tanks than does ASCE 7.
- API 620 Appendix L mandates lower R-values for these types of tanks than does ASCE 7.

Refrigerated Gas Liquid Storage Tank Clarification

- ASCE 7 Section 15.7.13, *Refrigerated Gas Liquid Storage Tanks and Vessels*, was one of the most poorly written sections in ASCE 7-05.
- Section 15.7.3 has now been revised to clearly state that tanks and facilities for the storage of liquefied hydrocarbons and refrigerated liquids must meet the requirements of ASCE 7.

Refrigerated Gas Liquid Storage Tank Clarification

- In other words, these structures must meet the requirements of the building code.
- Often, these types of structures are designed to other standards that specify a greater seismic demand than that required by ASCE 7.
- The changes to this ASCE 7 section do not override the stricter requirements of other standards but do invoke the ASCE 7 site specific procedures and the 80% floor limit on site specific ground motions.

Masonry Structures Clarification

- ASCE 7-05 Table 15.4-2 contained entries for reinforced and unreinforced masonry that differed substantially from similar entries in Table 12.2-1.
- The change made was intended to make Table 15.4-2 more consistent (but not exactly the same) with the limits and restrictions in Chapter 12 and to add specific detailing requirements for reinforced masonry.

Masonry Structures Clarification

Table 15.4-2 Seismic Coefficients for Nonbuilding Structures not Similar to Buildings

Nonbuilding Structure Type	Detailing Requirements[c]	R	Ω_0	C_d	Structural Height, h_n, Limits (ft)[ad]				
					B	C	D	E	F
All other reinforced masonry structures not similar to buildings detailed as intermediate reinforced masonry shear walls	14.4.1[f]	3	2	2.5	NL	NL	50	50	50
All other reinforced masonry structures not similar to buildings detailed as ordinary reinforced masonry shear walls	14.4.1	2	2.5	1.75	NL	160	NP	NP	NP
All other nonreinforced masonry structures not similar to buildings	14.4.1	1.25	2	1.5	NL	NL	NP	NP	NP

Questions?